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EVOLUTION OF ELEMENT MIGRATION DURING GEOLOGIC TIME[1,2]

by

A. A. Saukov

In selecting the topic for this address in accordance with the interests of A. E. Fersman, I have considered several aspects of migration, which was a topic of enduring and considerable interest to him; he considered it the most important in geochemistry, and he devoted much time to it (as in the second and third volumes of his "Geochemistry"). He wrote that "Migration appears to me the most important effect in nature; it determines all the various geocehmical reactions and complexes" ([9], vol. 2, p. 52).

Experience has shown that he was absolutely correct; there is now no doubt that migration is of exceptional importance in many theoretical problems and also in practical ones; migration forms the basis of new and progressive geochemical methods of locating mineral resources.

Ferman divided all migration factors into internal types (those proper to elements and compounds) and external types (those related to the situation in which the element occurs). My object here is to consider migration factors during geologic time, and we shall see that here there is an essential difference between the internal and external factors.

Internal factors such as nuclear charge, valence, and atomic (or ionic) radii have remained constant; the properties of the compounds have, correspondingly, been constant. It is true that the atomic weights of radioactive and radiogenic elements (U, Th, K, Pb, He, Ar) have changed because of alterations in isotopic composition, but these changes have had very little effect on the chemical properties of the elements, which are the ones that govern the capacity to migrate. The internal factors have been as we find them today throughout geologic time, for they reflect the structure of the atom, especially of the outer electron shells, which has remained the same.

The external factors have altered greatly during the history of the earth, as one may see from current natural processes and from the material relics of past epochs. This result is implied also by the historical principle, one of the guiding principles of dialectic materialism; the study of any object or phenomenon must include an examination of time-dependent (i. e., historical) changes. Our evidence confirms this general philosophic principle, and I now deal briefly with some aspects of this.

There is now no doubt that the absolute and relative amounts of the various elements have changed substantially during the history of the earth, partly by exchange between the earth and the cosmos, and partly by nuclear processes, which have been demonstrated for some elements and which are assumed for others. The exchange is continuous, as Vernadskiy has demonstrated; the earth receives matter in the form of meteorites, meteoritic dust, and cosmic rays. We have no precise information on the contributions from these various sources, but the influx at present is certainly small; Shmidt [11] assumed that the annual influx of meteoric material is 400 tons, but the latest evidence indicates that the true figure is nearer 10 or 20 tons per day. These are only rough figures, of course, since they are derived from observations on meteor showers; i. e., on bodies whose mass is 1 gm or more; virtually no allowance is made for meteoritic dust, the fall of which is not observable by ordinary methods and which can be collected only with great difficulty.

The total annual influx must undoubtedly be much greater than the above figures, but it is still very small relative to the mass of the earth (about 6×10^{21} tons). Shmidt's theory would imply that the influx was much greater in the past; he assigns the earth an age of 7.5×10^9 years, which would be equivalent in his theory to an annual influx of about 8×10^{11} tons. The initial influx was much larger, the flow gradually decreasing to the current level.

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[1]Evolyutsiya faktorov migratsii elementov v geologicheskoy istorii, (pp.3-16).

[2]Paper at the Second Fersman Lectures, 21 December 1960.

The composition of the material is much the same at all points, but its composition differs greatly from the mean composition of the crust; the reason is partly that the crust showed and still shows exchange with the deeper parts, and, as a result, the crust loses preferentially the iron-group elements, magnesium, sulfur, and so on, while the surface gains silicon, calcium, sodium, potassium, aluminium, the radioactive elements, and so on. The influx is now not large, so it does not alter the composition of the crust appreciably; but the effects may have been quite different in the past, in which case the composition of the crust could have varied quite rapidly.

A second source of material lies in cosmic rays; the primary radiation consists of charged particles, which are nuclei of various elements, mainly ones of low atomic number Z (H, He, with less Li, Be, B, C, N, and O, and still less of elements with $Z > 8$). If we take the proton content of the primary radiation as a unit, the He is 0.15, the Li, Be, and B are about 0.01, as are C, N, and O; the heavier elements account for only 0.003 [1]. The flux outside the atmosphere at high latitudes is about 10 particles per cm^2 per minute; if all are protons (mass 1.67×10^{-24} gm), and taking the surface of the earth as 5.1×10^{18} cm^2, we have that the earth receives 5.1×10^{19} particles per minute, which is equivalent to about 8×10^{-5} gm. In one year (525,600 minutes) this amounts to only 40 gm, which is negligible relative to the mass of the earth.

However, these particles have a mean energy of about 10^{10} ev (some as much as 10^{19} ev), and they collide with nuclei in the atmosphere, lithosphere, and hydrosphere to produce showers of electrons and nuclei, which contain mesons (unstable particles), which decay to other particles. The cosmic rays are very highly penetrating (far more so than gamma rays), for mesons are observable underground down to depths of 1 km or so. All the same, the total effect of these nuclear processes is not great, because the flux is so low; the energy flux is about 10^6 kw, which is negligible relative to the energy flux received from the sun.

The total influx from these sources is now not large, but it was probably much larger in the past. On the other hand, the earth is continually losing the lightest gases (hydrogen and helium), which are produced in the earth and which, when they reach the upper layers of the atmosphere, are lost as a result of the pressure of solar radiation. The process is very important for helium, which is an inert gas and so is not retained in the form of minerals. This is the reason for the very low abundance of helium, although it is continuously produced in many nuclear processes. It has been calculated that the helium now remaining is only 0.1% of that generated by nuclear processes during the history of the earth. Helium is second only to hydrogen in abundance in the cosmos. No such calculation can at present be made for hydrogen, for we do not know the amount initially present; but we can be quite certain that hydrogen in underground gases soon rises once it reaches the atmosphere and is rapidly lost from the earth.

The other gaseous elements are retained much more strongly by gravitation and so are lost only very slowly; but in the past, when the mass of the earth was much smaller, the loss could have been much more rapid. It is generally considered that the original atmosphere of the earth has long since been lost; Vinogradov ([4], p. 15) considers that temperatures in excess of 1000°K may occur at heights of about 1000 km, in which case the atmosphere would lose its hydrogen in 3600 years, its deuterium in 1.3×10^7, its tritium in 2.9×10^{10}, its He^3 in 2.9×10^{10}, its He^4 in 4×10^{13}, and its nitrogen in 10^{45}. The time for 2000°K are 1800 years for hydrogen, 2.4×10^7 for He^4, and 3.9×10^{22} for nitrogen. An age of 5×10^9 years for the earth would mean that all the hydrogen has been lost, and probably the helium too, and this for the existing gravitational field; the other gases would have been lost also if the earth was much smaller. The moon confirms this, for its mass is 1/81.5 of that of the earth; this explains its complete lack of atmosphere (any atmosphere is less than 1/2000 of that of the earth) in spite of its low temperature.

Radioactive decay is another way in which the composition of the earth can be altered. The natural radioelements are of two types, namely U^{238}, U^{235}, Th, decay products of these, and K^{40}, all of which are strongly radioactive, and the weakly radioactive Ca^{48}, Rb^{87}, Zr^{96}, In^{113}, In^{115}, Sn^{124}, Te^{130}, La^{138}, Nd^{150}, Sm^{147}, Lu^{176}, W^{180}, Re^{187}, and Bi^{209}. The half-lives in the first group range from 1.4×10^{10} years (Th) to 7.1×10^8 years (U^{235}), which imply that substantial proportions of them have decayed during the history of the earth. The law of decay is $N = N_0 \exp(-\lambda t)$, in which N_0 is the number of atoms at $t = 0$, N is the same t years later, and λ is the decay constant, being $0.693/T$, in which T is the half-life. This implies that the elements of short half-life must have been expecially abundant in the past; Voytkevich [5] states that 3×10^9 years ago there was 18 times as much U^{235} and 5.3 times as much K^{40}. The amount of U^{238} has diminished by about a quarter, and that of Th by a few percent.

The half-lives in the second group range from 6.1×10^{10} years (Rb^{87}) to 1.4×10^{21} years (Te^{130}); any changes in amounts of these have been quite negligible. It is possible that other isotopes are radioactive, but too weakly to be detected at present; Vernadskiy considered radioactivity to be a general property of matter.

These radioisotopes decay to stable isotopes of other elements; for example, one atom of U^{238} gives rise to one of Pb^{206} and eight of He, one of U^{235} gives one of Pb^{207} and seven of He, one of Th^{232} gives one of Pb^{208} and six of He, one of K^{40} gives one of Ar^{40}, one of Rb^{87} gives one of Sr^{87}, and so on. Helium, lead, and argon are formed in large amounts; almost all of the He^4 on the earth is radiogenic (from α-rays). The same applies to Ar^{40}, which is also the dominant isotope of argon (99.6%). Ordinary lead consists of Pb^{204} (1.48%), Pb^{206} (25.2%), Pb^{207} (21.7%), and Pb^{208} (51.7%); the latter three make up 98.52% of natural lead and are the decay products of U^{238}, U^{235}, and Th^{232}. Almost all the lead on the earth is radiogenic, and the amount of lead in earlier geologic epochs must have been much less than at present. These examples show that the composition of the earth has changed substantially during geologic time.

The energy balance has changed even more; all sources of energy on the earth are either cosmic (mainly the sun) or internal. Baranov ([1], p. 118) gives the following table for the energy fluxes from the various external sources:

Source	Erg/sec	Proportion of solar radiation
Sun	$1.76 \cdot 10^{24}$	1.00
Full moon	$3.09 \cdot 10^{19}$	$1.76 \cdot 10^{-5}$
Night sky	$2.61 \cdot 10^{17}$	$1.48 \cdot 10^{-7}$
Cosmic rays	$1.69 \cdot 10^{17}$	$9.26 \cdot 10^{-8}$
Meteors	$1.44 \cdot 10^{17}$	$8.18 \cdot 10^{-8}$

These show that the sun supplies nearly all of the energy (1.76×10^{24} erg/sec or 4.2×10^{16} cal/sec), while the total heat flow from within the earth is only 9×10^{12} cal/sec.

There are reasons for believing that the energy flux from the sun has not changed substantially during the history of the earth; this energy plays a major part in hypergene processes, and it is essential to living provesses and to the growth of green plants. There was no biogenic storage of solar energy until green plants appeared; here we have the essential difference between the abiogenic and biogenic periods. Some solar energy is transmitted deep into the earth, but the extent of the effect is not clear; the energy is that stored in fossilized material, in products of weathering, and perhaps in some crystals during hypergene alteration (conversion of Al from fourfold coordination to sixfold, according to Lebedev and Belov). The solar energy reaching the surface is thereby carried to great depths, where some of it is released. The extent of the release is unknown, though some processes are clearly negligible. However, the earth has its own more powerful heat sources, principally radioactive decay, whose importance became obvious when radioactivity was discovered in the early years of this century.

Voytkevich has calculated that the amounts (in units of 10^{18} cal/year) are now U^{238}, 171.8; U^{235}, 7.14; Th, 173,57; and K^{40}, 73.83 (the decay products being included in each case). The total is 4.25×10^{20} cal/year or 1.35×10^{13} cal/sec, which is very close to the outflow (9×10^{12} cal/sec), so nearly all the heat from within the earth is produced by radioactive decay. There are, however, other sources of heat within the earth; for example, differentiation (rise of lighter elements, sinking of heavier ones). Lyustikh has calculated that this process may produce 6×10^{27} erg/year (about 1.5×10^{20} cal), which is about 30% of the radiogenic heat.

An additional source of heat is tidal friction, derived from the rotation of the earth in the gravitational fields of the sun and moon [7]. This friction is supposed to have increased the period of rotation from 4 to 24 hours during the past 5 billion years, which would correspond to about 2.2×10^{30} cal, or 4×10^{20} cal/year on average. But most of this energy is released in the atmosphere and hydrosphere, and so escapes without affecting the depths of the earth; some is released in the solid parts of the earth, but the amount if small relative to the radiogenic heat.

There may also be exothermal reactions within the earth, but these are accompanied by endothermal ones, which may be more common; the final result may be an absorption of heat, for there is no reason to suppose that the reactions on balance are exothermal. We may sum up by saying that radiogenic heat is the most important at present; this is even more so for past geologic epochs when the proportion of radioactive elements was larger.

Some figures are given above for 3 billion years ago; then there was slightly more Th, about four times as much U^{238}, about 5.3 times as much U^{235}, and about 18 times as much K^{40}. Khlopin calculated that the heat release was then about five times the present level; subsequent revision of the data (Voytkevich) indicates that the factor for 3 billion years ago was about two and for 5 billion years was about 5.5. Vinogradov consideres that in the very early stages (5.5 billion years ago) the heat was sufficient to vaporize matter.

These results show that radiogenic heat was even more important in the past, when it must have activated colvanic and metamorphic processes; this feature must not be overlooked.

Biogenic factors are exceptionally important among the external factors that affect migration, as Vernadskiy and Vinogradov, the founders of biogeochemistry, have demonstrated. Living matter concentrates many elements; e. g., carbon as wood, coal, oil, carbonaceous shale, carbonates, and so on; also phosphorus, silicon, iron, and calcium in biogenic minerals, oxygen in the atmosphere, and so on. Living processes produce oxidixing agents (including free oxygen) and reducing agents (organic products in various forms, hydrogen sulfide, and so on). Elements having several valence states (Fe, Mn, V, Co, Ni, U, S, Se) are greatly influenced by redox processes, which may, for example, convert mobile forms into immobile ones. The various organic reducing agents were not present before life appeared on the earth, and nor was free oxygen, so redox processes were not nearly as important as at present. Geochemical processes were then very different, for many important redox processes did not occur.

Life arose perhaps 2 billion years ago; this is the age Ahrens gives for the blue-green algae in the siliceous slates of Ontario. Life appeared at first in certain parts of the sea and only gradually became adapted to conditions throughout the hydrosphere, in the upper part of the lithosphere, and in the lower part of the troposphere. Biogenic factors were at first unimportant, but they increased in scale and changed in kind as evolution proceeded. The most important stages as regards geochemistry were the production of green plants (these synthesize hydrocarbons and other compounds and release oxygen, by the utilization of CO_2, water, salts, and solar energy), the colonization of the land masses, and the appearance of the human race, whose activities are having an increasing effect on nature.

The first stage was especially important, for there was virtually no free oxygen before; much of the carbon was present as CO_2 in the atmosphere (the concentration in those times was much higher than at present). This feature affected the migration of elements of variable valence very much; for example, iron now migrates mainly by virtue of certain redox conditions, and the concentration of iron in sea water is only micrograms per liter, because the principal hydroxide, $Fe(OH)_3$, is virtually insoluble in water. Previously, CO_2 was abundant and oxygen was lacking, and the iron migrated from the land to the sea mainly as $Fe(HCO_3)_2$, which was present at high concentrations in the hydrosphere, for it is very soluble when the partial pressure of CO_2 is high. The situation altered radically when free oxygen appeared, for the dissolved ferrous iron was oxidized to the insoluble ferric form. This is probably the origin of the Precambrian iron ores, which occur on a vast scale over great areas; a characteristic feature of these is that they occur almost anywhere, not merely, as at present, near shorelines. No appreciable amount of iron could remain in solution subsequently, when oxygen was always present, so the earlier events could not be repeated; no iron ores could be deposited far from the shore, but they still could form in inshore waters, and all younger sedimentary iron ores have, in fact, been formed in this way. Precambrian jespilite iron-silica ores occur in the Americas, in Europe, in Asia, and in Australia; the known reserves are more than 3000 billion tons, and the figure is continually increasing as Precambrian rocks are examined. One example is the Kursk magnetic anomaly, where reserves of many billions of tons of high-grade ore have been discovered in recent years. Post-Algonkian sedimentary iron ores amount to only 135 billion tons, or less than 5% of the total; this illustrates the importance of the evolution of the atmosphere to the geochemistry of iron.

Manganese behaves very much as does iron in relation to oxygen; it migrates readily when there is abundant CO_2 and no oxygen, but it is precipitated as a hydrated higher oxide in the presence of oxygen. In fact, the main bodies of sedimentary manganese ores are associated with the Precambrian.

No such effect is known for bauxite, as we would expect, for aluminium has a fixed valence under natural conditions. Strakhov's diagram [8] illustrates the behavior of Fe, Mn, and Al.

The initial absence of free oxygen, and the probably long period of low abundance, must have affected the behavior of other elements. Weathering processes must have been different; physical weathering was present, but not biologic, while chemical weathering must have taken other forms in the absence of oxidation. In particular, sulfides could not have been oxidized to sulfates, so no sulfate could have accumulated in the sea; this must be the cause of the lack of gypsum, anhydrite, barite, and celestite in the oldest Precambrian rocks.

Many other minerals could not have existed in those times when free oxygen was lacking (e. g., higher oxides of many metals and metalloids, minerals containing Fe(III), S(VI), Mn(IV), V(V), U(VI), Se(VI), and so on). The number of possible minerals was thus much smaller, especially in view of the absence of caustobioliths and associated minerals of organic origin (resins, bitumens, and so on).

The abundant CO_2 also had pronounced effects, as in the migration of $Fe(HCO_3)_2$; other elements that migrate in response to abundant

CO_2 are Ca and Mg, which also form soluble bicarbonates, and these decompose to the insoluble carbonates when the CO_2 is removed. This must be the cause of the relative lack of chemically deposited limestones and similar rocks in the Precambrian; it may also be the cause of the lack of calcareous skeletons in Precambrian invertebrates, as Vinogradov has pointed out. The high partial pressure of CO_2 prevented the hydrosphere from becoming saturated with calcium; saturation was reached only when much of the CO_2 had been removed by plants. Although these invertebrates did not have calcified skeletons, there were calcareous algal even in Precambrian times; these consumed the CO_2 about them by photosynthesis, so calcium carbonate was deposited on them.

The second stage (colonization of the land) was also important. The first simple land plants appeared at the end of the Cambrian, but land plants reached full development only in the Devonian and (especially) the Carboniferous, when large amounts of organic matter accumulated on the land; deposits of coal and oil are related to these epochs and later ones.

Organic materials can adsorb various elements from dilute natural solutions, so a mass of organic material can have pronounced geochemical effects. The rate of accumulation of organic matter is dependent on the balance between autotrophic and heterotrophic organisms as well as on the conditions of preservation; this applies to all bioliths such as oil, coal, peat and combustible shale. The main body of preserved organic material occurs in the shales, especially in graphtolite shales, which are very common in the Cambrian and Silurian. These shales often contain large amounts of metals such as U, V, Mo, Ni, Co, Pb, and Cu, which are present partly on account of biologic functions of the elements (V, P. Cu) but mainly on account of adsorption from sea water during and after the formation of the sediments; the conditions were reductive and hydrogen sulfide was present, both features being characteristic of marine mud containing much organic matter. In particular, the high concentrations found in Cambrian and Silurian graptolite shales may be the result of the high concentrations then existing in the sea, where they had gradually accumulated in previous times. This influx into the sea was facilitated by the lack of land plants; there were not then the organic impediments that now retain these elements on the land.

Organic remains (soil, peat, coal) afterwards accumulated on the land, and many elements became unable to migrate to the sea; this is the reason why similar sediments from the Devonian onwards do not contain such large amounts of these elements.

This does not exhaust the role of organic barriers in geochemistry; the soil that now covers most parts of the dry land has very great effects on the behavior of many elements in the hypergene zone. There was no soil cover before the Devonian, and so many processes then took courses different from those we find today. However, this is a special topic falling outside the scope of this paper.

The human race appeared at a late stage in evolution; this introduced a new factor different in kind from all other natural factors, for man affects nature as a result of his social productive activities. Man survives and has survived because he has come to understand and alter nature. Man's early effects on nature were few and slight, but they steadily became more pronounced and more complex; within the space of a few thousand years (a time unimaginably short for most natural processes) they became comparable with or more important than some geochemical factors. These effects changed as the productive forces of society developed; their nature and scale are dependent on production methods. The organic world, the distribution of the elements, and the geography of plants and animals have all been affected by man's agricultural, mining, and technologic activities; natural associations have been destroyed and new ones created, many thousands of new compounds hitherto unknown have been made, and new elements and isotopes have been produced.

The geochemical effects of human activities have become increasingly important; Vernadskiy [3] in 1916 reckoned that man used 19 elements before the 18th century, 28 in that century, 50 in the 19th, and 59 at the start of the 20th. The list is now even longer, and it includes the transuranium elements as well as many radioactive isotopes. The scale of consumption has increased even more rapidly; Fersman's estimates of 1934 indicate that the consumption of iron, manganese, copper, and coal increased by a factor of more than 50 during the last century, the figure for aluminium, potassium, molybdenum, and tungsten being 200 to 1000 ([9], vol. 2, p. 298). The amounts of many minerals mined in the last 30 or 40 years may exceed the sum for all previous history; for example, the output of uranium, the most important material for nuclear industries, has increased from a few tons a year to many thousands in the space of 15 years.

The rates of growth have been especially high in the U. S. S. R., China, and other socialist countries; Vernadskiy's figures indicate that Tsarist Russia extracted only 17 elements in 1916, whereas now the list is very much longer, while the output of particular materials has increased by factors of hundreds or thousands.

The natural associations of elements built up over millions of years have been disrupted by man within the space of centuries; this is of

importance far outside geochemistry and must be considered ever more seriously as fossil sources become exhausted. It implies a need to give mining and prospecting a new base; lower grades of ore must be utilized, and new types of sources (e. g., nepheline, which Fersman proposes as a source of aluminium). We need new (including geochemical) means of locating ores not exposed at the surface. These trends will become increasingly important.

The climate is a factor that governs migration and that has changed during geologic time. Dokuchayev was the first to recognize its exceptional effects on hypergene processes in his theory of soil and climatic zones; these effects are now universally recognized. Weathering and migration are governed to a large extent by the air temperature, precipitation, and heat flow characteristics of the locality; these factors affect the processes directly and also through organisms which respond to very minor changes in warmth and humidity. The climate also affects the composition of eluvium, deluvium, and alluvium; in steppes, and especially in deserts, all these become rich in $CaCO_3$, and the solutions become weakly alkaline. This last feature implies a very low mobility for many elements such as Fe, Zn, Cu, Ni, Co, and Mn; the continental beds in depressed areas often become loaded with gypsum and salt.

Humid climates give a different geochemical setting; here the continental beds are neutral or weakly acid, which facilitates the loss of elements such as Ca, Cu, Zn, U, Mo, and sometimes Fe, Mn, and Co. Organic matter accumulates in depressed areas in the form of peat; the reducing conditions favor the movement of Fe, Mn, and other elements, which accumulate in places where oxidizing conditions prevail. This is the origin of bog iron ore, for example.

Unusual geochemical conditions occur in zones of permafrost, high aridity, and tropical conditions; unusual forms of migration occur in soils and rocks. These features must be considered in metallometric and hydrogeochemical surveys.

Allowance must be made for the major changes in climate during the history of the earth in any discussion of the historical aspects of geochemistry. There is much literature on this subject, which is well surveyed in Schwarzbach's book [10]. The evidence indicates that the climate of the earth as a whole has changed; warm periods were much more common and prolonged than cold ones. The general climate was especially warm in the Cretaceous; the Permian and Triassic were particularly arid, while the Late Carboniferous and Early Jurassic were very humid. Schwarzbach concludes from the migrations of the equatorial belt of reefs that the equator once lay much farther north; it gradually migrated south from the Cambrian (the first period for which the distribution of reefs can be established). Strakhov draws a similar conclusion from the distribution of arid and humid zones; he finds that the equator ran roughly along the line joining Belgium to the Donbass in the Carboniferous; the hot humid climate in that region gave rise to the coal of Britain, Belgium, France, Germany, and the Ukraine.

It is virtually proven that the climate changed repeatedly in the past; there is no major disagreement over the nature of the changes, but there is a wide divergence of views as to the causes. However, this topic takes us outside the scope of this paper.

To sum up, we may say that the major factors that affect the migration of the elements are the heat balance of the earth, the composition of the atmosphere, the climate, biogenic factors, and even the abundance of the elements themselves, all of which have varied pgreatly during geologic time. It is impossible to accept any other conclusion; e. g., Dobryanskiy's assertion [6] that "there is no reason to doubt that the geologic conditions on the earth were the same in all epochs". The same applies to Berg's statement ([2], p. 83) that "even in early Archeozoic times the land was subject to precisely the same weathering processes that occur in the latest epochs". These and other statements of uniformitarian type now seem unfounded.

The topics I have considered here are of major (importance to geochemistry and demand more detailed examination. The historical evolution of geochemical factors should form a separate division of geochemistry, which, by analogy with historical geology, may be called historical geochemistry.

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Institute of the Geology of Ore Deposits,
Petrology, Mineralogy, and Geochemistry
Academy of Sciences of the U. S. S. R.
Moscow

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ORIGIN OF THE HYBRID TRAPS OF THE PODKAMENNAYA TUNGUSKA SIBERIAN PLATFORM[1]

by

A. P. Lebedev

Descriptions are given of the following rocks occurring among hybrid trap bodies in the lower part of the Podkamennaya Tunguska River: 1) gabbro-diorite, monzonite, and leucodiorites, which are average in chemical composition but variable in texture and mineral composition, and 2) diorite pegmatites and granophyre, which are acid and in places rich in miarolitic cavities. The two groups differ in origin; the first crystallized from a trap melt of high acidity consequent upon contamination by adjacent rocks, while the second arose mainly via metasomatism produced by solutions rich in silica and alkalies.

The hybridization is considered to be associated with some definite types or parts of the trap magma, which are rich in volatiles either from the start or as a result of assimilation.

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1. INTRODUCTION

Assimilation was long ago recognized as an important process in the formation of igneous bodies in geosynclinal regions. Much less if known about its role in platform processes, especially as regards the trap formations (which are derived from basalt magmas) so typical of platforms. The trap intrusions are relatively small and are generally of uniform petrographic composition; moreover, they are poorly exposed, so signs of hybridization and contamination, which give rise to acid and intermediate rocks of anomalous composition, have not been examined. The usual tendency is to assign the origin of all these types to differentiation processes alone, although a detailed analysis shows that they include rock types of assimilation origin; in general, assimilation in all its forms is much more important than is commonly assumed.

Here, I describe the petrography of the hybrid traps in the basin of the Podkamennaya Tunguska (west part of the Siberian platform), which I examined in 1958.

2. GEOLOGIC CONDITIONS AROUND THE TRAPS

Nearly all of the rocks in these intrusions in the lower reaches of the river are of the type most common in the Tunguska syncline; they have been described already [4, 5, 8, 10]. Two groups may be distinguished, and with them two series of traps, namely 1) undifferentiated traps (olivine gabbro-diorite) and 2) somewhat later differentiated traps derived from a differentiated trap magma. There is a third (hybrid) rock group, which is dealt with below; this is more acid and occurs mainly at the edges of the traps of the second group. The exposures are best in the valley of the Podkamennaya Tunguska around the Vel'ma ridges (Figure 1).

The zone of hybrid traps is about 800 m long and lies along the left bank near the island of Kukuy; the visible thickness ranges from 3 to 10 m, and the body is generally of a sheet type. Underlying the hybrid rocks are traps (of olivine dolerite) of the underlying Vel'ma sill, and so we may say that the traps are associated with the top of this sill. Above this there lies somewhat altered quartzitic and arkosic sandstones, which contain bands of argillite from the Baykit formation (Lower Ordovician). In the southeast part of the zone (upstream) we find a very variable texture in the hybrid rocks; the grain size changes sharply from fine to coarse, with leucocratic medium-grained rocks of diorite type predominating. The upper parts of the zone contain a network of thin irregular veins of pink aplite 5 to 10 cm wide; at the bottom, as the normal trap is approached, the grain size of the diorite increases. In places the diorite grades into more mesocratic rocks of monzonite or gabbro-syenite type, with medium or large grains, and very commonly there are prismatic

[1]K geneiesu gibridnykh trappov Podkamennoy Tungyski (Sibirskaya platforma), (pp. 17-36).

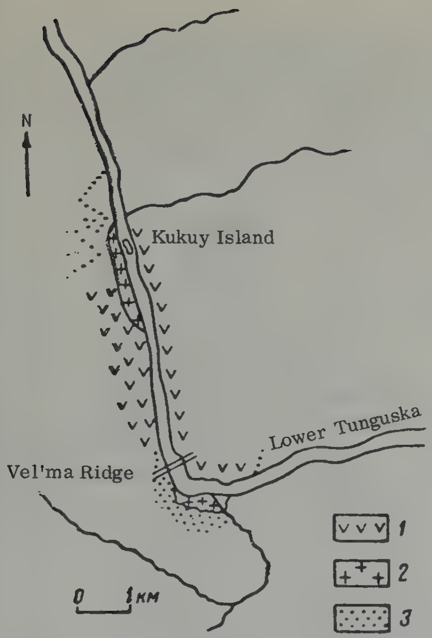

FIGURE 1. Distribution of the hybrid traps described here

1 - normal traps (gabbro-dolerites); 2 - hybrid traps; 3 - Quaternary deposits.

inclusions of a dark silicate; here we also find some quartzitized sandstone xenoliths with irregular melted outlines.

The zone retains much the same structure farther to the northwest along the strike (downstream; Figure 2). In the upper parts we find flat or irregular areas of leucocratic fine-grained rocks of aplite and granophyre type, which may correspond to previous xenoliths of sediments subsequently completely altered. The main rocks are rather coarser, pinkish, and leucocratic, with a variable texture; these may be called subalkaline diorite pegmatites and granophyre. The finer-grained varieties predominate higher up (near the sandstones), and these in places contain many small miaroles containing free crystals of quartz, amethyst, zeolites, and chloritic minerals. The diorite pegmatities contain intergrowths of crystals of chloritized amphibole 10 to 15 cm long; in places there are accumulations of magnetite several centimeters in diameter. There are rare inclusions of fine-grained dolerite whose composition is similar to that of the underlying trap sill; there are also rare, small xenoliths of hornblende-impregnated mudstone.

Similar hybrid rocks of intermediate or acid composition are known, in other parts of this region. For example, a sheet of acid diorite pegmatite of similar lie, size, and petrography occurs on this river on the left bank above the Vel'ma Ridge; this is about 500 m long and 20 to 25 m wide in the exposure. In the west part of the Bol'shoy Porog intrusion (near the mouth of the Khadatkan) there is a large irregular area of diorite pegmatities among trachytic gabbro diabases; this has a vertical extent of over 2 m. The rocks vary greatly in composition and texture; they are yellow-gray, leucocratic, and with dark radiating clusters of composite pyroxene crystals up to 5 cm long; they also contain garnet and sphene. Similar diorite pegmatites occur in deluvium and screes along the Stolbova and Maygun, and around the Shukhmikha intrusion. Geologic surveys indicate that such rocks also occur in the divide between the Podkamennaya Tunguska and the Bakhta, in part in the form of dikes (?); in particular, they are found at several points along the Dzheltul and other tributaries of the Bakhta. Further east, Gurevich reports an area in the basin of the Tychan 4.5 km below the mouth of the Kevde, where there is a raised region 600 x 1000 m; the base of this consists of normal olivine traps, and the top of diorit, which contains up to 58% of SiO_2 and 20% of potash feldspar. These latter rocks belong to the upper part of a horizontal sheet trap intrusion. Again, along the Tychan there are exposures of bostonite and syenite aplite, which probably belong to the same complex. Along the Yudolomo (a tributory of the Podkamennaya Tunguska) there are sandstones of the Baykit formation, which Yuon states are converted to granophyres at some points of contact with the traps.

That is, although the acid and intermediate rocks occur in only a few places in the trap complex, their regional occurrence in the Siberian platform is fairly considerable, for they occur in a variety of places.

3. PETROGRAPHY OF THE HYBRID TRAPS

The hybrid rocks are very heterogeneous and variable; they are often difficult to name within the existing petrographic nomenclature, so the divisions made below are somewhat arbitrary, for the types grade gradually one into another.

Gabbro-diorite

These have a variable structure (panidimorphic to pegmatoid) and are fine-grained. These pinkish or light-gray rocks are commonly taxitic, with patches of larger grain size (Figure 3); their main components are andesine, alkali feldspar, some quartz, amphibole, and sphene.

The feldspars are mainly much albitized plagioclase with relicts of andesine (45, 47, and

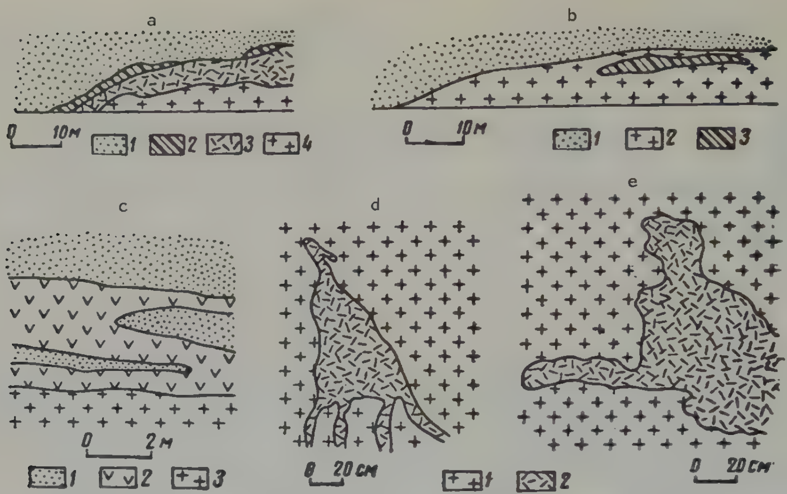

FIGURE 2. Structures of parts of hybrid traps

a1 - Lower Ordovician sandstone and quartzite; a2 - gabbro-diorite and monzonite; a3 - diorite pegmatites; a4 - dolerite; b1 - Lower Ordovician and sandstone and quartzite; b2 - diorite pegmatites; b3 - granophyre; c1 - Lower Ordovician sandstone and quartzite; c2 - gabbro-diorite and monzonite; c3 - diorite pegmatites; d - lens of diorite pegmatite in trachytic gabbro-dolerite: 1 - gabbro-dolerite; 2 - diorite pegmatites; e - the same lens in transverse section (symbols as before).

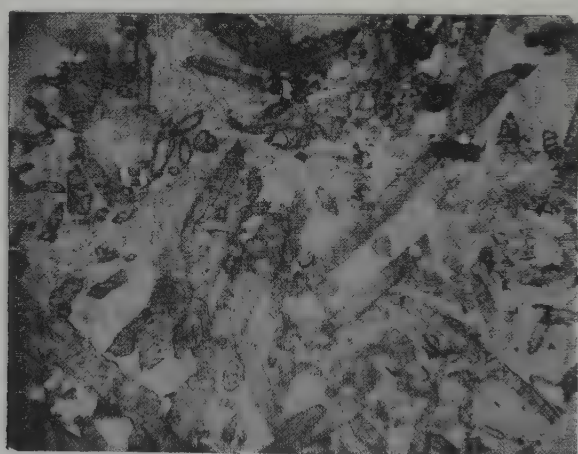

FIGURE 3. Gabbro-diorite; prismatic needles of pyroxene against a granophyre-plagioclase background

Specimen 157, 7x, no analyzer.

48 on the Ab-An scale), with rather less sodium-potassium feldspar. The albite ingrowths contain thin parallel plates of optically negative K-Na feldspar.

The amphibole forms prismatic needles, which replace pyroxene (to judge from the relicts), and has two generations: 1) dominant generation green, with γ green, β to a yellowish-green, $\gamma = 1.728$, $\alpha = 0.700$, and iron content 90%; 2) second (minor) generation, brown, brownish on γ, light green to yellow on β and α, $\gamma = 1.707$, $\alpha = 1.686$, iron content 55%.

Accessory minerals always present are sphene (in fair quantity), apatite, zircon, and titanomagnetite.

Monzonites and Leucodiorites

These are light-gray rocks, finer or medium-rained, with many transitions (even within a ingle core) from leucocratic fine-grained to ioritic medium-grained varieties. These occur n the hybrid formations near Vil'ma Ridge and more extensively) around the Shukhmikha in-rusion in exposures along the left bank of the odkamennaya Tunguska.

The main body of the rock consists of plagio-lase and has a hypidiomorphic texture; the road tabular feldspar grains are 2 to 3 mm ong. Against this background we find small, nore idiomorphic, clusters of amphibole and linopyroxene as well as irregular grains of nuch decomposed potassium feldspar (see 'able 1 for an approximate composition for one ariety). All members of the group show great ariations in the balance of minerals; some

it forms small pale-green prisms with rough edges (it grades into aegirine-augite); $\gamma = 1.720$, $\alpha = 1.686$, and $c{:}\gamma = 42°$, which corresponds to a ferroaugite of composition $En_{37}Wo_{23}Fs_{22}$.

The biotite forms thin leaves as overgrowths on the pyroxene and ore minerals; $\beta = 1.631$.

Accessory minerals are abundant; the clusters contain apatite, which forms many inclusions in the feldspar. The sphene has large irregular grains, and there are large clusters of orthite, which is of the type found in the diorite pegmatites. Zircon is always present as small idiomorphic prisms, in places cloudy.

In general, all these hybrid rocks show advanced autometamorphism (albitization, actinolitization, chloritization, abundant sphene and apatite).

Table 1

Mineral Compositions of Hybrid Traps in Volume %

Rock	Leuco-dolerite	Diorite-pegmatite		Granophyre	
	Specimen 151a	Specimen 1546	Specimen 154a	Specimen 155a	Specimen 162
Basic plagioclase	—	44.0	26.3	23.7	11.0
Alkali feldspar (single grains)	77.0	2.4	1.2	—	—
Amphibole	13.2	0.3	0.2	1.4	13.2
Clinopyroxene	1.8	0.6	2.2	—	—
Quartz (single grains)	—	25.1	13.2	—	14.3
Granophyre (quartz + alkali feldspar)	—	22.9	52.5	58.8	60.8
Titanomagnetite	8.0	3.2	3.5	4.8	0.4
Chlorite	—	—	—	7.3	—
Accessory minerals	—	1.5	0.9	4.0	0.3

reas are almost plagioclasite, others gabbro-iorite. The ore minerals are prominent.

The plagioclase has zoned crystals, which re albitized to the extent of 50% or more. The rimary plagioclase is close to labradorite An 58-60). The plagioclase at Shukhmikha is artly replaced by radiating intergrowths of eolite (thomsonite).

The amphibole crystals have large concave reas, which gives them a metasomatic appearnce; γ to β is light green, while α is pale ellowish-green; $c{:}\gamma = 16°$, $\gamma = 1.705$, and $\alpha = 1.672$.

The clinopyroxene is amphibolized and is resent only in the Shukhmikha intrusion, where

Subalkaline Diroite Pegmatites

These occur near the top of the lower Vel'ma trap sill, near Kukuy Island, at the mouth of the Khakdasis, and near the first Vel'ma Ridge. They also occur in the Bol'shoy Porog and Shukhmikha intrusions and in a few other places. They are most abundant among the hybrid traps, and everywhere they grade into granophyres, monzonites, and other rocks of this group via intermediate types. In places they occur as sharply distinct areas in normal traps. They are light gray (Figures 4 and 5) or pinkish coarse-grained leucocratic rocks having very variable textures (the grains range in size from under 1 mm to over 10 cm) and very unevenly distributed dark minerals, which usually have grains smaller than those of the feldspars,

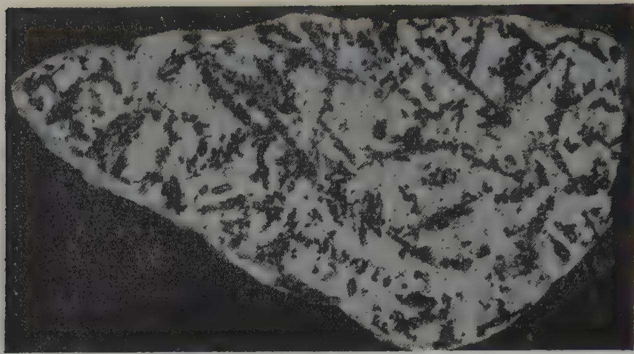

FIGURE 4. Diorite-pegmatite; light background of albitized plagioclase and granophyre, dark columnar crystals of amphibolized pyroxene.

Hand specimen, natural size.

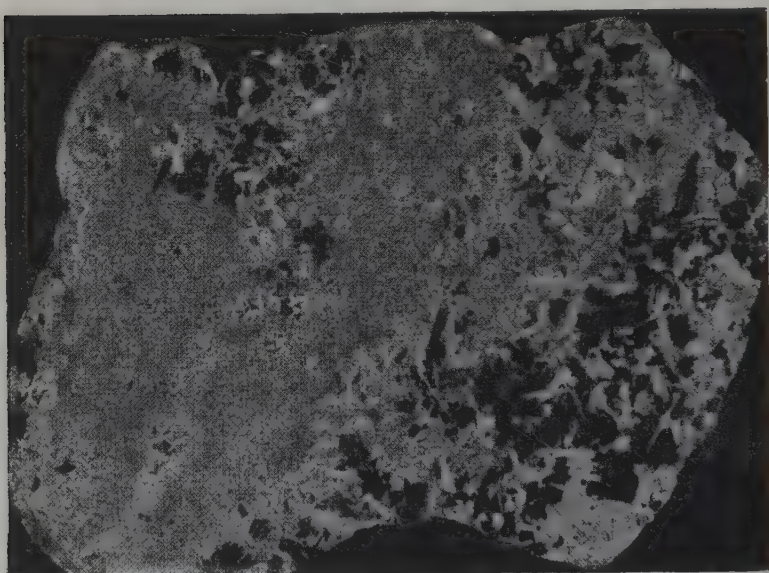

FIGURE 5. Irregular taxitic alternation of diorite-pegmatite (dark) with granophyre (light).

Hand specimen, 4/5 natural size.

although grains up to 8 or 10 cm long do occur. The main mass of the rock consists of subidiomorphic plagioclase, with the spaces filled by a micropegmatite of very small grain size, in which are scattered isolated prismatic clumps of amphibole (the most common), clinopyroxene (usually with some amphibole), and titanomagnetite, the last being in places the only dark component. The dark minerals are usually the most idiomorphic. The balance of the minerals varies greatly, but these general descriptions apply to all varieties. Table 1 gives the means from five counts. Autometasomatism is prominent but variable; in places actinolite, zeolites, and other hydrated minerals are abundant.

The quartz forms irregular grains in the micropegmatite; larger isolated grains are not very common. The feldspar in the granophyre, where it can be identified, is albite; it is optically positive, of low refractive index, grayish in color between parallel polarizers, and usually slightly replitized. Some of the feldspar, which has a brownish pelitization color, is probably K-Na feldspar, as the presence of potash in the diorite pegmatites would indicate. In one single case microcline was identified;

this had $P_\gamma = 78°$, $P_\beta = 14°$, $P_\alpha = 84°$, and $2V = -80°$.

The plagioclase forms tabular idiomorphic crystals; changes in the parts remaining free from albitization are indicated by the zoned structure and the presence of andesine (An 35-38, 42, 45) at the centers. The transitions between zones are usually gradual; the difference between the margin and center is usually only 5 to 8 units on the An scale. The albite occurs as laths within the grain and as a thick envelope (Figure 6); the large grains of andesine have been most altered, the small grains commonly being fresh. The albitization was a lengthy process, which began in the late magmatic stages (when the regularly oriented albite envelopes were produced) and which later gave rise to the perthitic ingrowths. There are also areas with independent (probably late) small elongated areas of albite cemented by quartz.

FIGURE 6. Diorite-pegmatite; large grain of basic plagioclase albitized at the edges, amphibole crystal on the left.

Specimen 154a, 18x, with analyzer.

The amphibole forms long prismatic idiomorphic crystals; the grains commonly have a gridded structure and a fan-shaped outline, which gives them (in conjunction with the abundant small quartz and feldspar inclusions) a metasomatic appearance. The large prisms sometimes can be seen under high magnification to consist of several grains differing in orientation. The crystals are in places enveloped by small sphene crystals. The amphibole is of the following three types: 1) green, with γ green; β to a light green, $c:\gamma$ 12°, 14°, 16°, 2V from -54° to -78°, $\gamma = 1.685$, $\alpha = 1.657$, iron content (Sobolev) 53-55%; 2) brownish, with γ yellowish green, β to a pale yellow-green, $c:\gamma$ 16-18°, 2V from -67 to -74°, $\gamma = 1.714$, $\alpha = 1.678$, and iron content 68-83%; and 3) greenish blue, with γ greenish blue, β to a pale green, $c:\gamma = 20°$, $2V = -65°$, and $\gamma = 1.730$. The brown variety is of high iron content. A single crystal may consist of more than one type; the brown color may be stronger at the center or in patches. These color variations within a crystal of uniform structure may indicate variations in iron content or in the state of oxidation of the iron; in either case, they mean that the melt was disturbed while it was crystallizing, which reflects the complex history of the hybrid rock.

The primary hornblende may be replaced by platelets of actinolite; the extent of the replacement varies greatly even within a single section.

The clinopyroxene (which is not always present) also forms prismatic idiomorphic crystals, which are usually only 2 to 6 mm long. The grains are irregular and in places have a weak green color. The mineral is a ferroaugite containing much iron: 1) $\gamma = 1.742$, $\alpha = 1.714$; 2) $\gamma = 1.734$, $\alpha = 1.707$; 3) $\gamma = 1.745$, $\alpha = 1.716$. Polysynthetic twins are present, and in places the green color is stronger at the edges (on account of the presence of aegirine-augite); part of the grain may be replaced by actinolite crystals. About half the pyroxene in rock from the Khadatkan River is replaced by foliated

biotite, which is a sign of alkali autometasomatism, as is the presence of the aegirine molecule. Finely divided magnetite is also present in this case.

The thomsonite and analcime occur as replacement products from plagioclase, in which they form platy or radiating aggregates.

The titanomagnetite and ilmenite are present in variable amounts, which may be in excess of those for normal traps. The grains vary in shape from irregular angular to skeletal and platy; they are commonly trapped between grains of amphibole and are commonly associated with actinolite. There are always margins or inclusions of sphene, which clearly replaces the ore mineral; this would indicate that the ore mineral is rich in titanium. The shape of the grains and the constant association with amphibole would indicate that the titanomagnetite was formed at the end of the crystallization of the silicate, which I interpret as products from iron-rich drops of melt produced by liquation [6].

The sphene forms overgrowths and rims on the titanomagnetite; it also occurs as independent crystals up to 0.5 mm long of characteristic wedge shape.

which are generally abundant; these are of two types (Figure 7): 1) cloudy needles in the mesostasis; 2) larger prismatic crystals with many microscopic inclusions of biotite and amphibole, which commonly cut the plagioclase. These may contain minute gas or liquid inclusions, which are concentrated near the center and are responsible for the cloudiness. Analysis indicates that the material is fluorapatite.[2]

Garnet occurs in isolated instances; it is present as rare irregular grains up to 0.8 mm in diameter in the diorite pegmatite from a lens on the Khadatkan, and here it invades other minerals. It is yellowish and has anomalous birefringence at the edges; the refractive index (1.880) corresponds to andradite.

Zircon is always present as prisms 0.01 to 0.03 mm long enclosed in grains of the dark silicates; it occurs regularly with a late actinolite-chlorite-mica association. It is commonly surrounded by pheochroic halos, which indicate that it contains radioelements; X-ray fluorescence spectra confirm this. There are dark areas within the zircon, which may be inclusions.

The orthite forms prismatic rods up to 2 mm long; these have skeletal growth forms and

FIGURE 7. Crystal of apatite 1.5 mm long enclosed in pyroxene

Specimen 154, 80x, no analyzer.

The epidote is usually present as thick yellowish prisms in intergrowths with amphibole.

The apatite occurs as prismatic crystals,

[2]See Ye.D. Nadezhdina on "Accessory minerals of the traps in the lower reaches of the Podkamennaya Tunguska" (Trudy I.G.E.M. Akademiya Nauk S.S.S.R., vyp. 55, 1961) for details on the accessory minerals of hybrid and normal traps.

sometimes entirely irregular xenomorphic outlines. The brownish color becomes darker towards the center; the pleochroism is from brownish on γ to yellow on α. The darker internal parts usually have a more regular outline, which may mean that the outer lighter margin is a late overgrowth (replacement product); this has been assumed for orthite in some metamorphic rocks. For example, Rein (1952) states that the granite gneisses of the Black Forest always contain 0.7 to 0.8% orthite, which shows signs of regeneration in the form of irregular margins; these are evidence of the repeated action of hot solutions.

Granophyres are also very common in the hybrid complex; they are pale gray or pink almost hololeucocratic rocks consisting of granophyre or micropegmatite (intergrowths of quartz and alkali feldspar). These intergrowths vary in size, and the crystals in them may be up to several millimeters long. These are accompanied by occasional small irregular clusters of quartz, laths of basic plagioclase, and dark minerals, the last being drawn out into bands (Figure 8). The plagioclase, dark

universal-stage determination gave $P_\gamma = 86°$, $P_\beta = 18°$, $P_\alpha = 72°$, and $2V = +86°$, which indicates that the material is 12 on the albite-oligoclase scale. Table 1 indicates the relations between the main components in the granophyres. The larger plagioclase laths are zoned and are highly albitized andesine (An 35-38 and 41 at the center).

The K-Na feldspar forms small irregular areas among the intergrowths; these are brownish, pelitized, and in places have a network structure, which indicates that they are of microcline.

The amphibole consists of long, largely unaltered crystals with rounded ends, which are composite; γ is green with a slight blue tinge, while α is light yellow-green. Crystals with weak zoning give $2V = -60°$ at the edges and $-65°$ at the center; $\gamma = 1.743$ and $\alpha = 1.712$ for the center.

The clinopyroxene occurs as rare small prisms, which are much altered (actinolitized), are light green, and have irregular edges;

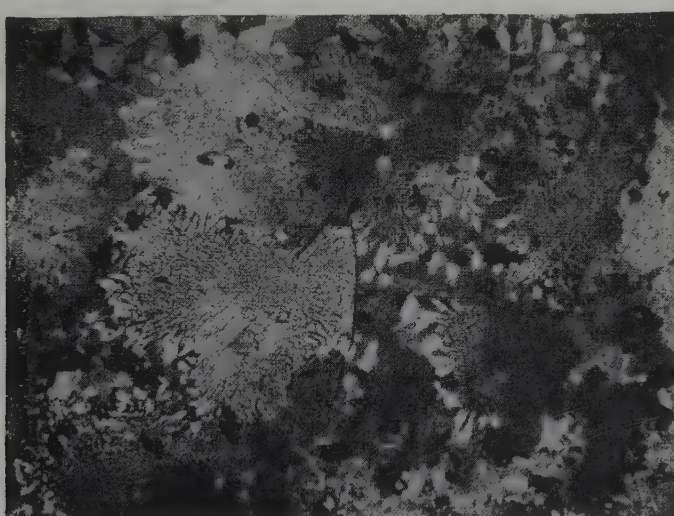

FIGURE 8. Granophyre. Intergrowths of alkali feldspar and quartz. Specimen 164, 200 x, with analyzer.

minerals, and accessory minerals are very unevenly distributed; the amounts, grain size, and grain shape vary greatly. These features show that the granophyres were formed under rapidly changing conditions, as is characteristic of hybrid rocks.

The feldspar is mainly albite and has a small-scale texture; in places its sign can be determined as optically positive. A single

$\gamma = 1.720$, $\alpha = 1.696$, and $2V = +52°$, which corresponds to $En_{38}Wo_{23}Fs_{37}$. In one case I found aegirine-augite ($c{:}\gamma = 54°$, $2V = -70°$).

Epidote occurs as rare small irregular grains on pyroxene.

Thomsonite occurs in the mesostasis.

The accessory minerals are as for the

Table 2

Chemical Compositions of Hybrid Traps

Components	Podkamennaya Tunguska						Karroo metasomatic granophyres (South Africa)			granophyres of magmatic origin		average types of acid magmatic rocks (Daly)	
	gabbro-diorite		monzonite		diorite pegmatites	grano-phyre				hedenbergite granophyre Skaergaard	devitrified glass lens in tholeite Kinkell	mean grano-diorite	mean granite
	Kukuy Island	Upper Vel'ma Ridge	Shukhmikha River	Kukuy Island	Kukuy Island	Kukuy Island							
	1	2	3	4	5	6	7	8	9	10	11	12	13
SiO_2	51.79	54.47	55.48	58.18	65.82	71.59	59.22	63.3	70.8	58.81	72.4	65.01	69.21
TiO_2	2.47	0.97	0.07	0.70	1.04	0.55	0.92	1.5	0.7	1.26	0.2	0.57	0.41
Al_2O_3	11.79	8.14	17.88	18.90	10.93	11.70	5.36	14.2	14.0	12.02	13.1	15.94	14.41
Fe_2O_3	3.86	2.93	0.98	5.95	5.84	1.24	4.11	1.1	0.1	5.77	1.1	1.74	1.98
FeO	10.51	7.74	8.68	3.43	3.58	3.75	3.44	6.6	3.9	9.38	1.6	2.65	1.67
MgO	1.64	6.33	4.60	1.79	1.21	0.48	3.56	1.8	1.5	0.72	0.5	1.91	1.15
MnO	0,16	0.11	0.17	0.08	0.06	0.03	0.80	0.1	traces	0.21	traces	0.07	0.12
CaO	9.97	14.70	8.12	3.50	3.30	3,05	5.64	4.0	2.0	5.03	2.8	4.42	2.19
Na_2O	3.89	1.76	2.07	4.03	4.27	2.96	2,48	5.1	3.9	3.91	2.6	3.70	3.48
K_2O	2.03	1.57	1.31	3.11	1.52	3.79	1.90	1,9	3.0	2.39	4.6	2.75	4.23
H_2O^+	0.30	0.51	0.64	0,52	0,58	0.26	—	—	—	—	—	1.04	0.85
H_2O^-	0.52	0.27			0.38	0.05	—	—	—	—	—	0.20	
P_2O_5	0.87	not det'd.	0,14	0.55	not det'd.	not det'd.	0.90	0.1	0.1	0.71	0.4		0.30
Sum	99.86	99.50	100.58	100,75	99.54	99.45							
$\frac{FeO+Fe_2O_3}{FeO+Fe_2O_3+MgO}$	99	61	69	84	89	90	68	68	71	95	84	69	77

Note: Analyses in columns 1-6 are my own, performed in the chemical laboratory of I. G. E. M., Academy of Sciences; 7-9 are from [12]; 10 is from [24]; 11 is from [25]; and 12 and 13 are Daly's average types.

diorite pegmatites, and they have the same features.

4. CHEMICAL FEATURES OF THE HYBRID TRAPS

The rocks of this group are very variable in chemical composition; Table 2 gives analyses for typical representatives. The silica content cause the rocks to be classified as acid and intermediate types; the rocks have some features that distinguish them from ones of the same acidity in the normal igneous series, as we may see by plotting the analyses on a Zavaritskiy diagram (Figure 9). The curves for the various alkali-metal and alkaline-earth oxides are not smooth when the rocks are arranged in order of SiO_2 content, as the variation diagram (Figure 10) shows. The anomalies are very prominent for CaO, which at first becomes more abundant, then less abundant, and finally remains at a constant level in the intermediate and acid rocks; magnesia and alumina do the same. The alkali metals also show irregular variations, especially sodium, which rises sharply in amount in the intermediate range but falls again in the acid range. The iron factor shows no regular trend.

These rocks show many of the features reported [16] for metasomatic granophyres among the Karroo dolerites; the analyses of these are given for comparison. Further, Gorai [17], who has made a special study of granophyres of igneous and metasomatic types, finds that the latter type contains more alumina and a higher ratio of MgO to Fe_2O_3 + FeO (relative to the former type); there are certain other distinctive features. This is so also for the granophyres

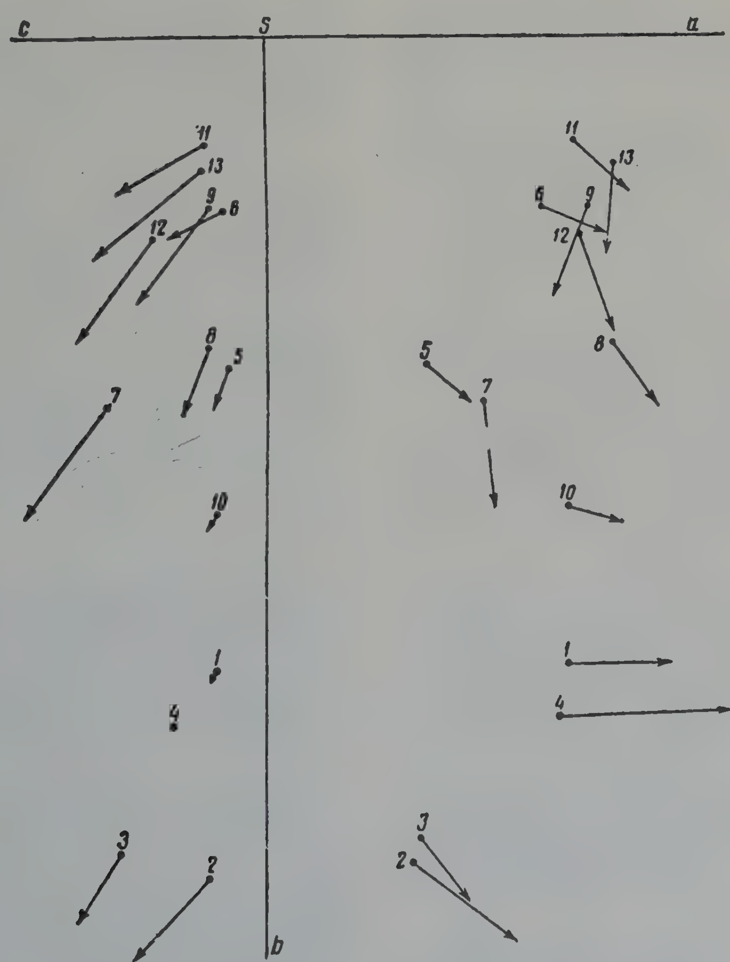

FIGURE 9. Petrochemical diagram of the hybrid traps

The numbers are those of the analyses in Table 2.

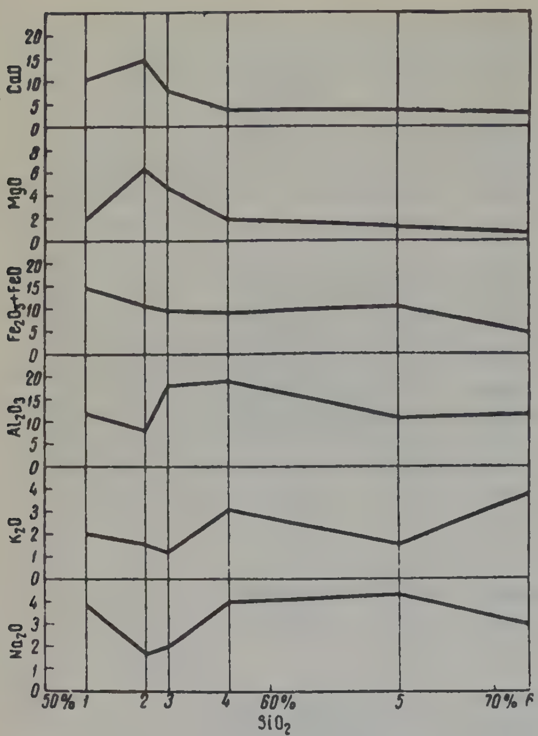

FIGURE 10. Variation diagram with respect to SiO_2 for the main oxides in hybrid traps traps.

described here relative to Daly's mean composition for granites and granodiorites, and also to ones probably derived from basalt magmas (the Skaergaard and Kinkell intrusions). The increased amounts of Cr and Ni in my specimens are in agreement with Gorai's [16] conclusions on metasomatic granophyres.

5. ORIGINS

The hybrid traps are distinctive in chemical composition, petrography, and geologic position, in all of which they differ greatly from the ordinary trap rocks and from normal igneous rocks of the same acidity. Special formation conditions must be assumed.

Similar acid and intermediate rocks occur in other formations derived from magmas of basalt, dolerite, and gabbroid types. Some that have been given detailed petrographic attention (but which sometimes lack detailed geologic description) are as follows.

The trap massif of Anakit (Lower Tunguska) has [10] exposures of pale fine-grained rocks resembling granite aplites; these consist of albite, microcline, anorthoclase (6), quartz (as a micropegmatite and as isolated grains), iron amphibole, sphene, and orthite. They are analogous to alkali granite in composition. Sobolev also states that leucocratic diabase pegmatites occur at the mouth of the Bugarikta, where they form an area among normal traps.

Masaytis [8] describes rocks of similar composition as occurring in the Alamzhakh differentiated trap intrusion; these he calls them quartz gabbro (they have up to 15% quartz) and granophyre, and they vary greatly in composition. He considers them differentiation products from a trap magma, but their great petrographic variation indicates that they are of various origins, being in part assimilation products. Some of them are very similar to the above hybrid traps (granophyres containing aegirine, quartz-oligoclasites).

Vakar (1952) states that a trap chonolite near L. Taymyr has streaky areas of irregular shape in olivine dolerite; the rocks include micropegmatite-diabase, quartz monzonite, quartz syenite, and microcline granite. They have a general similarity to the above hybrid traps, and they are clearly associated with variously altered xenoliths of Permian sandstone and siltstone.

Test [11] states that acid granophyres in the Anabar trap intrusions in places form vein-like bodies, whose origin he ascribes to extraction to an acid eutectic from the adjacent sediments by the trap magma.

Ravich and Chayka [9] report alaskite and amphibole granites and diorites as present in a large dolerite intrusion at Kiryamka (Taymyr); these they consider were formed from a trap magma contaminated by terrigenous sediments. They call them granitoid on account of some features of composition and texture, but they do not discuss their origin in detail.

Yakovleva [15] and Godlevskiy [1] state that the upper parts of the differentiated ore-bearing trap sills in the Noril'sk region are composed of hybrid rocks (quartz diorite to granite), which consist of orthoclase, quartz, micropegmatite, and 10 to 13% amphibole and chlorite; they were formed when the traps interacted with the overlying acid sediments.

Vladimirov finds that the Morgudol trap sill near Bratsk has an acid cover of granophyre, which lies on a diabase-pegmatite horizon composing the upper part of the differentiated intrusion. This granophyre has a decidedly metasomatic appearance; it tends to displace the diabases and the adjacent sediments (argillite and siltstone of the Bratsk formation, Ordovician). The hybrid zones again have miarolitic cavities filled with chlorite and zeolites.

There is also other evidence of assimilation of acid material by acid traps [2, 6].

Examples from other regions are as follows.

The Karroo dolerites (South Africa) show remarkable dolerite-pegmatites and granophyres formed by interaction with xenoliths of Permian sandstone [12]. Acid albite pegmatites occur in the upper parts of the Permian dolerite sills of Pennsylvania; Tomlinson [22] considers these to have been formed by the assimilation of at least 6% of acid material from the overlying rocks.

Tomkieff [23] reports partial assimilation and mobilization of the material of a polymict tuffaceous sandstone at a contact with a small body of gabbro-dolerite in Ireland. The sandstone was here partly melted and was converted to a vitreous (buchite) rock containing an acid glass and microliths of clinopyroxene.

The Proterozoic diabase Logan sills (north side of Lake Superior) are described [16] as having a zone of syenite and granophyre (redrock) of hybrid type at their contacts with clay shale. These are supposed to have arisen by assimilation of adjacent rocks, which are supposed to be granite lying at some depth rather than the nearby shale.

Chumakov [14] states that diabase dikes lying among Rapakivi granites in the Kola Peninsula are penetrated by a network of granophyre veins and even contain up to 7% of granophyre in the mesostasis in places. These acid rocks are assumed to have been formed from an acid palingentic magma that was formed from the granites by the diabase magma and then was injected into the diabase. The resulting acid and intermediate rocks are assumed to be associated with infiltration metasomatism and further magmatic replacement.

Other examples of this process are known from Fennoscandia for diabases lying among gneisses (Precambrian) and granites. Laitakari [20] states that an olivine-diabase sill among Rapadkivi granites in southeastern Finland has veins of an unusual rock of aplite type; these veins are up to 70 cm wide and penetrate into the diabase from the (older) granite or from granite xenoliths. The diabase becomes enriched in granophyre at the points where it merges with the veins. The veins are explained as an acid eutectic material of aplite type extracted from the granite.

The diabases of Satakunta, Finland, also lie among granites and contain [19] veins of regenerated granite up to 2 cm across, which emerge from the older rock. These veins are somewhat enriched in bases (especially Mg) relative to the granite, because these are the most mobile under these conditions.

Leighton [21] describes a gabbro-granophyre transition via intermediate rocks of diorite type for the Ashland gabbro massif in Wisconsin. The granophyre is considered to have arisen from an acid magma that was produced at depth by the gabbroid magma as a result of assimilation; this further reacted with the gabbroid magma to give hybrid diorites. There is no brecciation, so the acid material must have entered the gabbro mainly by diffusion; the rate of this is governed by the temperature gradient and by the difference in the chemical activities.

This short review shows that these acid and intermediate rock types can be very varied in petrography and in position. Hybrid rocks resulting from assimilation undoubtedly play an important part here, as well as types derived by direct differentiation from the parent magma.

The origin of the hybrid rocks of the Podkamennaya Tunguska is not very easy to establish, because the various features of the composition and position of these rocks are given a variety of genetic interpretations. Some consider all acid rocks of the Siberian trap complex to be solely products of differentiation by crystallization [8, 10]; Tomkieff [23] gives the same explanation for the acid parts of the Whin Sill, as does Hetz [18] for the granophyre areas of the diabase sills of Pennsylvania. However, some features make this explanation difficult to apply here.

The direct products of differentiation here are only the syngenetic pegmatoid areas that appear in the trap sills; here the general course of the crystallization is responsible for the local production of an intermediate or acid pegmatoid residue, for the areas are fairly evenly distributed. On the other hand, the acid and intermediate rocks of the Vel'ma sill occur only in special parts near the top contact; the extent of these areas bears no direct relation to the size of the intrusion, and they occur only near the contact zone, in which they differ greatly from the dolerite-pegmatite areas. This very uneven spatial distribution extends also to the general area in which these acid rocks occur; if they were a normal result of progressive crystallization, we would expect to find them widely and uniformly distributed among the trap intrusions of the region. Further, the petrographic features prevent us from considering them as normal products of differentiation; they vary greatly in texture and structure, their mineralogic composition is very variable, recrystallization and metasomatism are prominent (the plagioclase and pyroxene are attacked and replaced by granophyre), and so on.

These rocks may have been formed by the partial or complete assimilation of more acid country rocks (here Ordovician sandstone and argillite), which gave rise to a series of rocks grading from unaltered sediment to

uncontaminated trap rock. This gives us a reasonable explanation of some hitherto inexplicable features, namely 1) the association with contact zones, 2) the unusual features of the texture and composition, which distinguish them from rocks of magmatic origin, and 3) the presence of rocks intermediate between trap and granophyre types. Of course, this raises some new problems, such as the mechanism of assimilation, the site of the process (directly at the contact or at lower levels), the detailed nature of the changes (purely metasomatic or partial melting), and so on; only preliminary answers can be given to many of these.

This series of rocks can be divided into 1) those of intermediate composition (ones of gabbro-diorite and monzonite types) and 2) acid and leucocratic rocks (ones of granophyre and diorite-pegmatite types).

Those of the first group have a general magmatic appearance, although even here we find metasomatic replacement of the earlier minerals; but this is a minor feature. The texture is very uneven and is dominated by long prismatic crystals of amphibole and pyroxene, which vary greatly in texture and composition. These features all indicate that the rocks crystallized under rapidly varying conditions (this was not so for the main body of the trap intrusion) from a highly heterogeneous melt much contaminated by material from the adjacent rocks.

Those of the second group are more acid; the structures and relations between the minerals indicate that they were produced mainly by metasomatism. The most characteristic component is granophyre, which extensively replaces the basic plagioclase and pyroxene originally present; moreover the plagioclase is altered to albite and the pyroxene to aegirine (alkali and silica metasomatism). The pyroxene and amphibole also show characteristic signs of blastic growth.

Some areas also show signs of later (?) Fe-Ca-Mg metasomatism (chlorite, sphene, apatite, and garnet are present, and there are rims on the orthite). It is quite possible that a quartz-feldspar eutectic was extracted from the adjacent rocks (as occurred in some of the instances quoted above), especially in view of the raised temperature in the hybridization zone. However, the structures point rather to a dominant process of infiltration metasomatism. The extent of the alteration varies greatly throughout the zone, which is a result of variations in the pressure and in other factors that play a decisive part in metasomatism [3].

The volatiles play a more prominent part in the region of the hybrid traps, for there are many miarolitic cavities, much apatite, and an abundance of minerals containing water (chlorite, zeolites, and so on).

All these features indicate that these hybrid traps were formed under very unusual conditions; they belong to the hybrid formation resulting from interaction between the trap magma and the nearby sediments, the products being a contaminated (diorite) magma and a series of hot hydrothermal solutions that caused strong metasomatism. That process was stimulated by the increased amounts of volatiles in the magma itself and in the assimilated rocks (H_2O, CO_2, P, F).

Now, I shall consider the sources of the mineralizers that entered the assimilation zone when the hybrid rocks were being formed. One feature that points to the sediments as the source of some of these volatiles is the finding of large boulders of microconglomerate rich in apatite in screes around the Kukuy sill (on the right bank of the Podkamennaya Tunguska). The Ordovician deposits in the lower parts of the river are rich in phosphorite (there are even phosphorite deposits, which have been surveyed), so these conglomerates may be altered phosphoritic rocks which, if partly assimilated, would bring in much phosphorus and so would increase the assimilation capacity of the magma.

Of course, the magma may have become locally enriched in volatiles as it cooled; the volatiles in a crystallizing trap have been shown to be unevenly distributed, as we may see from the varying distribution of enriched dolerite-pegmatite facies in the traps [6].

We have seen above that hybrid traps occur in many parts of theSiberian platform, but they cover no great area and occur in association with normal traps only exceptionally. This may seem difficult to explain, for terrigenous rocks of acid composition (sandstone, siltstone) occur wherever we find the Ordovician and the Permo-Triassic in the Siberian platform. The explanation would appear to be that these hybrid rocks have certain specific features, especially abundance of volatiles, which may well have been even more abundant during the crystallization. These hybrid rocks may rise in association with normal traps only under certain conditions, namely when a highly differentiated trap magma much enriched in volatiles interacts with acid country rocks. Such an interaction cannot occur in nature even under these conditions, for volatile-rich traps are commoner than hybrid traps; the tectonic setting must also favor the reaction.

This situation may occur if the source channel is of suitable shape or if the intrusion is contained under rocks of low permeability. A detailed study of the geologic setting in each particular case is needed in order to elucidate this.

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Institute of the Geology of Ore Deposits,
Petrology, Mineralogy, and Geochemistry
Academy of Sciences of the U. S. S. R.
Moscow

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PETROGENETIC FEATURES OF THE MESOZOIC INTRUSIVES OF THE NORTHEASTERN LOW CAUCASUS, AZERBAIJAN S.S.R.[1]

by

G. I. Kerimov

The composition of the parent magma is discussed by reference to variations in the composition of the Kedabek group of intrusions and to the part played by assimilation in producing the various facies.

* * * * *

The Mesozoic intrusions of Azerbaijan are mainly granitic; they lie in the Somkhita-Karabakh zone along a narrow belt in the northeast of the Low Caucasus (Figure 1). All the intrusions are concentrated within a small area if we exclude that at Makhmana. Many geologic and petrographic studies have been made on the various massifs [2-4, 7, 10, 11, 13, 15-18], but the petrology of the massifs has been neglected, apart from my study of 1958 of the Kedabek group.

Figure 1 shows that here the largest massifs are those of Kedabek, Shamkir, Novo Gorelovka, Barum Barsum, Atakabek-Slavyanka, Dzhagir Chay, Kabakhtepa, Dashbulag, Shamkhor Chay, Dashkesan, Zurnabad, and Mekhmana; there are also many apophyses from these.

Previous workers have treated these massifs as being all of the same age and phase; i. e., as being only particular laccolithic exposures of a common batholith.

Recent work [9] has shown that the intrusions differ in age; Kashkay [7] and I [10, 11] have shown that the Dashkesan and Kedabek groups have several phases and facies. Almost all of the granitic massifs lie within the Gek-Gel'-Shamkhor uplift, whereas the Dashkesan and Kedabek intrusions (which have gabbros from the first phase) lie within the Dashkesan synclinorium.

The massifs of the same age lie within the Somkhita-Karabakh geotectonic zone and have many tectonic, petrologic, and geochemical features in common; petrographically speaking, they are all very similar. The Kedabek group has had the most detailed petrologic study, and all others are examined in reference to it. The scope of this article prevents me from dealing with many very interesting aspects of the problem, though.

COMPOSITION VARIATIONS AND PROBABLE EFFECTS OF ASSIMILATION

There is a marked and fairly regular change in the petrographic composition of the Kedabek group from northeast to southwest (my observations of 1958). Primarily, this appears as characteristic changes in the mineral composition as the purer (more acid) granitoids are displaced by more contaminated varieties. The Barum Barsum massif has granodiorite predominant; this is followed by adamellite and then by quartz diorite (varieties of granite porphyry subordinate). At Novo Gorelovka we have hornblende quartz diorite (contaminated varieties occur only at the margins), whereas at Kedabek we have contaminated quartz diorite, with normal (hornblende) quartz diorite somewhat less abundant and with very little granodiorite and tonalite-banatite. The plagioclase content of the Barum Barsum granodiorite varies very little (49 to 52%), while the plagioclase itself only ranges from 35 to 47 on the Ab-An scale (40 is found in the granite porphyry varieties alone); this is entirely normal for granodiorite; it indicates that the plagioclase in this massif is primary. This granodiorite contains much (8 to 17%) potash feldspar, in this respect ti differs from all Mesozoic granitoids on the northeast of the Low Caucasus.

Further, the granitoids of the Kedabek

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[1]Petrogeneticheskiye osobennosti Mezozoyskikh intruzivov Severo-Vostochnoy chasti malogo Kavkaza (Azerbaydzhanskaya S.S.R.), (pp. 37-44).

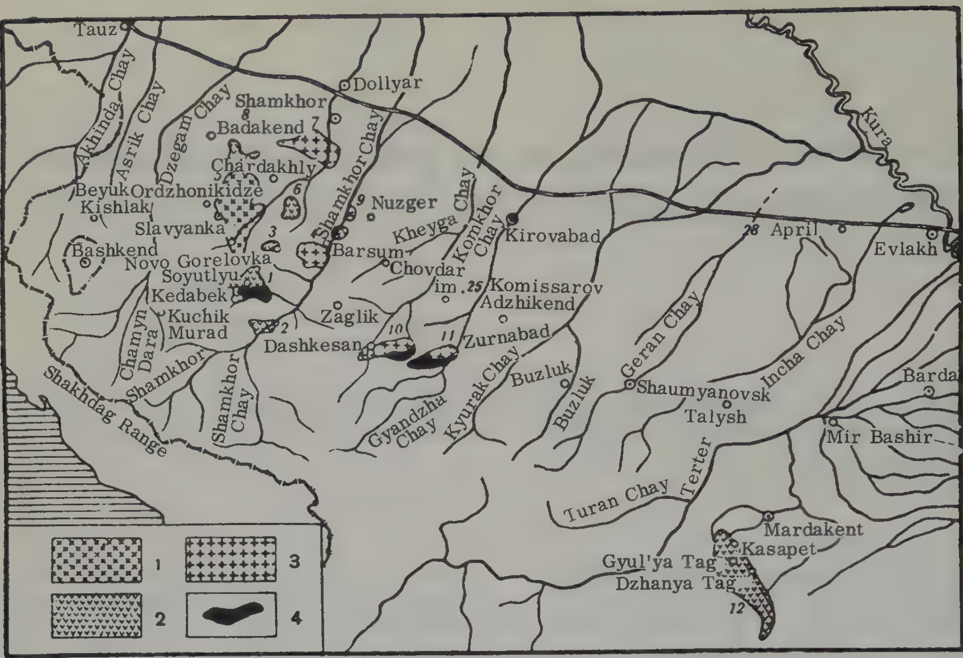

FIGURE 1. Location of the intrusions in the northeastern Low Caucasus

Numbers on map: 1 - plagiogranite; 2 - quartz diorite with subordinate tonalite, banatite, and granodiorite; 3 - granodiorite with subordinate banatite, tonalite, and quartz diorite; 4 - gabbro, gabbro-norite, gabbro-diorite, and diorite; 1 - Kedabek; 2 - Shamkir; 3 - Novo Gorelovka; 4 - Barum Barsum; 5 - Atabek-Slavyanka; 6 - Dzhagir Chay; 7 - Gabakhtapa; 8 - Dashbulag; 9 - Shamkhor Chay; 10 - Dashkesan; 11 - Zurnabad; 12 - Mekhmana.

intrusions contain microcline (and orthoclase); this is the first reported occurrence for the Mesozoic granitoirs in this part of the Low Caucasus. The quartz content of the granodiorite is 22 to 27%, which also corresponds to a normal composition for the magma. The biotite and hornblende content is generally within normal limits; the magma may have been very slightly enriched in certain elements by contamination from adjacent basic and intermediate porphyrites.

The Kedabek massif itself differs from the Barum Barsum intrusion in being very much hybrid. The rocks are mainly quartz diorite, tonalite-banatite and granodiorite being very much subordinate. The acid plagioclases (33-44) are accompanied by somewhat more basic ones (45-55), which are secondary. Colored minerals (including secondary ones derived from the famic minerals) are abundant and are commonly somewhat in excess of normal (up to 32%). Biotite and pyroxenes (the latter in places very abundant and usually very much uralitized) are often present.

The variations in the proportion of femic minerals imply that material has been introduced from the country rocks which have locally overloaded the magma with iron, magnesium, and (in places) aluminium; the quartz diorite at the contacts with the gabbroids and limestone have the highest content of colored components (gabbro xenoliths are present). The xenoliths have also been altered by exchange. There is no doubt that the magma which gave rise to the Kedabek massif had incorporated gabbroic material; it had also taken material of intermediate or basic composition from igneous and pyroclastic rocks of the Middle (and in places Upper) Jurassic, as well as Upper Jurassic limestones. These various rocks had a variety of effects on the granitoids, on the marginal facies, and on the residual melts (which gave the vein series).

The basic rocks (gabbroids) and limestone must have affected the differentiation, for they would raise the proportions of Fe and Mg in the contaminated rocks.

CHEMISTRY AND FACIES OF THE INTRUSIONS

Some twenty complete analyses are available for several rock species for the Kedabek group; this gives an indication of the part played by

assimilation. There are also some analyses for the country rocks.

In general, the Barum Barsum granitoids show a fairly close correlation between chemical composition and mineral composition; the overall composition corresponds to that of plagioclase, and this implies that the plagioclase within the range 35-37 is primary. This agrees with Korzhinskiy's view [12] that the plagioclase is usually of constant composition within a given granitoid intrusion. Very little material from country rocks has been incorporated in this massif; these rocks are intermediate and basic porphyrites (Middle Jurassic lower Volcanic beds) and Upper Bajocian acid quartz porphyries, so the effects are to be expected to be very different. The porphyrites would bring in Fe, Mg, and some Ca, which would reduce the proportion of SiO_2; whereas the quartz porphyries would introduce SiO_2 and Na_2O, and would reduce the proportions of Fe, Mg, and Ca.

The plagioclase in the Kedabek massif is more basic (up to 44), and there are also even more basic secondary plagioclases (45-55). Assimilation (especially from gabbroids and limestone) is much more prominent here; there are increased amounts of Fe, Mg, Ca, and (in part) Al, while the proportion of SiO_2 is lower. Adjacent intermediate and acid igneous rocks (porphyrites, quartz porphyries) could not have given this effect, especially in view of the fact that the granitoid magma contained somewhat more silica than normal.

The Kedabek, Novo-Gorelovka, Shamkir, and Barum Barsum massifs all show characteristic marginal facies in the form of eruptive breccias, which are derived from uptake of the Jurassic extrusive and pyroclastic rocks (kotlyar remarks on this). This marginal facies is more melanocratic at the contacts with the porphyrites (especially those in the lower volcanic beds); the rocks commonly grade into diorite and gabbro-diorite, but these are of very limited extent (Novo Gorelovka). The facies is usually more leucocratic when the adjacent rocks are quartz porphyries. Assimilation is never very important, and the edge facies do not differ greatly in composition from the central parts. Naturally, a granitoid magma is altered when it assimilates gabbroids, but the changes are relatively minor and are confined to the belt around the contact with the long-solidified gabbroids; for this reason I shall not consider them further.

The basic rocks (especially gabbroids) acted as major sources of ore elements, and they introduced substantial amounts of Fe and Mg, with rather less Al. Spectral analyses of the granitoids (first and second phases) show also that the Kedabek granitoids have been contaminated with elements characteristic of basic rocks alone; e. g., Ni, Co, Cr, and (in part) V; these granitoids contain amounts of these unusual for an acid magma, whereas those of Barum Barsum do not. This is, of course, to be ascribed to assimilation from the gabbroids of elements not typical of acid magmas (Ni, Co, Cr, and V) at Kedabek.

Table 1

Main oxides	I	II	III	IV
SiO_2	69.33	52.45	60.89	60.88
Al_2O_3	15.24	22.39	18.81	16.43
$Fe_2O_3 + FeO$	4.95	10.17	6.86	6.86
MgO	1.36	3.75	2.55	2.42
CaO	2.42	8.34	5.38	6.33
Na_2O	4.07	1.69	2.88	3.40
K_2O	1.87	0.31	1.04	1.05

I — mean composition of granodiorites, Barum Barsum massif;
II — mean composition of gabbros, Kedabek massif;
III — probable composition calculated from I and II on 1:1 basis;
IV — mean composition of granodiorites, Kedabek massif.

Analyses of the gabbroids (Kedabek) and granodiorite (Barum Barsum) correspond with these features of the assimilation. Table 1 gives analyses; column III represents the probable mean composition, which corresponds almost exactly with the mean composition of the hybrid quartz diorite (column IV). The slight deviation towards high CaO and reduced Al_2O_3 in the latter are the result of assimilation of limestone on a small scale in the Kedabek massif.

Similar effects have often been reported;

Table 2

Facies	volume percent	No. of analyses	Arithmetic means			
			a	*c*	*b*	*S*
Gabbro, gabbro-diorite, gabbro-norite, & feldspar pyroxenite	10	6	4.7	9.8	22.6	61.2
Diorite	4	4	9.5	8.6	14.1	67.9
Quartz diorite, tonalite, and banatite	59.6	7	9.0	6.1	14.1	70.7
Granodiorite and adamellite	26.4	3	11.3	2.8	9.2	76.7

Dolomanova [5] observes (for eastern Transbaykal) that the intrusion was produced in a complex tectonic setting from a magma rich in volatiles (especially B and F), which were derived from extensive assimilation, contamination, and granitization in the endo- and exocontact zones. The hybrid granite porphyries are enriched in biotite and plagioclase (which is very basic), as well as in V, Ni, Cr, and Co.

COMPOSITION OF THE PARENT MAGMA

The origin of igneous rocks and the number of parent magmas are topics of major importance in petrology; there are many widely divergent views. This is partly a result of the complexity of the problem and of the difficulty of making direct observations on magmatic foci. It is commonly accepted that there are distinct genetic complexes of igneous rocks having basaltic and granitic compositions; some would also distinguish a third genetic type (ultrabasic intrusions), but these are of very limited occurrence. Differentiation and assimilation are responsible for the variety of rocks produced by each type of initial magma.

The rocks in the group of intrusions considered here are the products of normal differentiation (assimilation, contamination, and hybridization did occur, but only on a small scale), and so the main interest centers around the mean composition of the magma, which gave rise to gabbroid and granitoid intrusions. To this end, following Zavaritskiy, I have calculated the arithmetic means for each facies (Table 2). The weighted means for the average magma incorporate allowances for the abundance of each facies:

Table 3 gives the values for the parent magma, for the average quartz diorite, and for the average tonalite (the latter two after Daly); the parent magma clearly falls between the latter two rock types, although it lies nearer to the quartz diorite.

Granitoids are more abundant than gabbroids on the northeast side of the Low Caucasus, but Kashkay has shown that gabbroids are abundant in the Dashkesan-Zurnabad massif as an independent phase; I have observed them near the village of Bayan [8], and fresh occurrences are continually being reported for the northeastern part of the Low Caucasus; e. g., in the foothills of the Nuzger Plateau (Shikhalibeyli et al [19]).

Another important feature to be considered in the calculations is the composition of the extrusive formations, which are genetically related to the later orogenic intrusions. This relation may be demonstrated reasonably directly in most parts of the area. The extrusive activity coincided mainly with phases of predominant descending movement in geosynclines, whereas the syntectonic intrusions were associated with folding. This genetic relation exists, for example, between the Upper Bajocian quartz porphyries and the plagiogranites of the Atabek-Slavyanka massif. Abdullayev [1] has also remarked on this relation. There is also no doubt that the Early Cretaceous intrusions are genetically related to the Middle Jurassic extrusives of intermediate (in places basic) composition. In places, however, there are extensive basic extrusives (diorite, augite and diabase porphyrites, diabase, and gabbroic diabase);

$$a = \frac{10\times4.7+4\times9.5+59.6\times9.0+26.4\times11.3}{10+4+59.6+26.4} = 9.2$$

$$c = \frac{10\times9.8+4\times8.6+59.6\times6.1+26.4\times2.8}{10+4+59.6+26.4} = 5.7$$

$$b = \frac{10\times22.6+4\times14.1+59.5\times14.1+26.4\times9.2}{10+4+59.6+26.4} = 13.6$$

$$S = \frac{10\times61.2+4\times67.9+59.6\times70.7+26.4\times76.7}{10+4+59.6+26.4} = 71.2$$

Table 3

Parent magma for Kedabek group				Average quartz diorite (Daly)				Average tonalite (Daly)			
a	*c*	*b*	*S*	*a*	*c*	*b*	*S*	*a*	*c*	*b*	*S*
9.2	5.7	13.6	71.2	10.6	5.7	11.7	72.0	9.1	7.0	11.7	72.2

these Upper Jurassic basic lava flows are very common around the Dashkesan massif.

This gives us reason to suppose that the Kedabek group was formed from a quartz-diorite magma. Here results of Solovkin [15] on the Dashkesan intrusion are significant; he questioned Luchitskiy, Kremchukov, and Sitkovskiy's explanation (that the gabbros and gabbroic diabases are the result of assimilation of limestone by a granodiorite magma) and demonstrated by calculation that a granodiorite magma can be differentiated to give gabbros without undergoing any special change in composition (but, of course, only in certain proportions). Solovkin showed that a granodiorite magma could give rise to a more or less typcial gabbro of about 10% of the mass. His conclusions: 1) the assimilation of limestone (of CaO) by a granodiorite magma cannot give rise to gabbroid and diorite facies, and 2) the small gabbroid bodies in this formation can be derived from a granodiorite magma alone, or from a quarts-diorite one, without assimilation of CaO. This conclusion as to the parent magma at Dashkesan is in agreement with mine for the Kedabed group.

The petrogetetic features of the Kedabek group are quite distinctive and are not in accordance with previous ideas; our picture of the differentiation of these intrusions needs radical revision. I consider that the evolution of the parent magma may be represented as shown in the diagram above:

Feldspar pyroxenite (subordinate)

gabbro, gabbro-diorite ← gabbro-diorite ← diorite ← quartz-diorite magma → tonalite-banatite → granodiorite → adamellite → aplite

aplite → pegmatites → quartz veins

aplite → orthoclase aplite, plagioclase aplite

My results show that the Kedabek group is probably the result of differentiation of an intermediate quartz diorite, which gave rise to all gabbroids and granitoids in this belt (apart from the Atabek-Slavyanka and Shamkhor Chay Middle Jurassic plagiogranite massifs). However, further work is needed; in particular, we require many more analyses of the gabbroids and granitoids in the other massifs.

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Institute of Geology
Academy of Sciences of Azerbaijan
Baku

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TECTONICS, MAGMATISM, AND ACID GROUND WATER OF THE MOUNT ELBRUS REGION

by

Yu. P. Masurenkov

The studies of the salt and gas content of the carbonated mineral springs of the Caucasus have had a long and complicated history: at present we cannot say that the problem has been solved even in general, as one may see from the numerous mutually exclusive hypotheses. I do not propose to deal with the problem as a whole, but I must point out that a major role has been assigned to volcanic processes by Karstens, Ogilvie, Gerasimov, Lebedev, Rengarten, Slavyanov, I. G. Kuznetsov, and S. S. Kuznetsov, to mention only a few. Betekhtin considers that many mineral springs in volcanic areas "are residual hydrothermal solutions that have lost most of their metallic components before reaching the surface" ([3], p. 235). Vlasov [5] takes the same view as do others.

This view has fallen out of favor with hydrogeologists in the past decade, as we may see from the hypothesis that NaCl carbonated waters are related to fossil sea water, a concept applied even to areas in which there are no sediments.

Ovchinnikov, Yrublevskiy, and others [6, 9-11] deny that volcanic processes play any part in producing the salts in the mineral springs of the mountainous central Caucasus (a region of mainly ancient crystalline rocks).

There is much better agreement on the origin of the carbonic acid; the majority view is that it arises from magmatic processes, although some are inclined to give preference to thermal metamorphism in isolation from such processes. In any case, processes at depth are thought to be decisive. As yet there have been no detailed studies on this subject; the existing views are based largely on likely situations.

The water is of complex origin; governed by the overlying rocks (sedimentary, metamorphic, or igneous), by interactions with seeping solutions, by the geologic and thermal setting, and by tectonic processes. The effects of volcanic processes are obvious in regions of current volcanic activity, which affects the composition of the water. Finally, the climate determines the amount of precipitation, which also affects the composition greatly.

Neglect of any of these factors leads to unsound deductions as to the genesis of the water; any methods to be used must take account of these natural processes as fully as possible.

The north Elbrus region is especially suitable for this purpose, for here we find many different types of spring; moreover, the highly complicated questions of interactions with sediments are virtually completely eliminated, which is especially valuable, for there is a tendency at present to explain some components (e. g., chloride) in terms of interactions with sediments containing residual sea water.

I began my study of the Cenozoic activity in the Elbrus volcanic region in 1953, and this detailed study has revealed some interesting regularities in the location and composition of the waters. A previous paper [8] deals with the general tectonics and volcanic activity, but I need to add some fresh detail on the aspects of interest here. The geologic history of the region enables us to deduce the general laws governing the spatial distribution of volcanic products. In particular, the region lies within the Elbrus-Stavropol transverse uplift; the formation of the eastern and western boundaries of this uplift was one of the decisive stages in that activity.

The western boundary began to appear in the Paleozoic in the form of a transverse structure, which formed the eastern margin of a geosyncline; it ran along the divide between the Kuban and the Malka. The origin of the eastern boundary can be traced back only as far as the Triassic, when a submerged zone was formed east of the Chegem; thick sandy clay beds were deposited, and there was a downwarp in the

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[1] Tektonika, magmatizm i uglekislye mineralnye vody Priel'brus'ya, ((pp. 45-57).

basin of the Teberda and Kuban. The transverse uplift was present also in the Triassic, as is indicated by a change in thickness and by an alteration in facies from uplift to downwarp. Increased transgression is Dogger times somewhat reduced these differences; erosion before the Late Jurassic was especially active around the Elbrus-Stavropol uplift, where the Callovian and higher beds of the Jurassic cover deposits of Dogger, Triassic, and Paleozoic age. This is best seen in the youngest parts of the uplift (the Glavnyy Range and the zone of longitudinal depressions) and north of the Khasaut (also north of Khabaz). The Upper Jurassic beds thicken continuously towards the western and eastern downwarps. The region of greatest depression shifted to the north in the Cretaceous and Tertiary, which is responsible for the form of the Pyatigorsk uplift.

The Elbrus-Stavropol uplift may be divided into several structural elements, each of which belongs to a tectonic zone of the northern Caucasus and has its own tectonic history. The southernmost part of the uplift lies around the Glavnyy Range and so shows the largest vertical displacement from the Paleozoic to the present. The Promezhutochnaya (intermediate) zone of depressions is one of very large differential movements in narrow tectonic wedges. The extent of these movements within the uplift is much less than that of those in more westerly regions. The Chegem-Makla subzone (of relatively stable uplifts) is the eastern end of the Peredovoy Range, whose tectonic history appears in the subzone on a very small scale, if at all. The Kislovodsk-Makla zone further north contains almost no Jurassic beds.

These parts of the uplift are joined along fault lines, which are commonly accepted as having localized volcanic activity; many have acted as channels of egress for magma. However, this one-sided approach does not give us a true picture of the disposition of the products. It has been shown that the faults in the zone of depressions and in adjacent parts of the Glavnyy Range are related to the Mesozoic porphyries of the Cherek Bezengiyevskiy, to the Kuban porphyrites, and to the Cenozoic volcanic formations of the Cherek and Elbrus; but it is impossible to say on this basis why they occur as isolated large areas.

Ths history of the uplift and volcanic activity indicates that the two are related in space and time; the products of Mesozoic and Cenozoic activity occur mainly at the margins of the uplift; i. e., at points of flexure joining the uplift to the downwarps to the east and west. These transverse flexures consist of a series of faults in the region of the crystalline base; they are generally parallel and of various ages. The system of transverse faults is very common along the eastern margin in the basins of the Chegem and Cherek; the zone of depressions and the Chegem-Makla subzone are here dissected by the transverse faults of the Chegem basin. In the more northerly regions we find continuous Upper Jurassic, Cretaceous, and Tertiary beds, and here the eastern margin of the uplift appears as a flexure of these beds towards the Nal'chik depression. The western margin appears in much the same way, but less clearly; it is very well seen as a stepwise rise in the Apsheron peneplain (about 1000 m from the left bank of the Kuban to the right). The various faults and flexures at the margin form broad weakened zones. The lateral margins of the uplift have migrated respectively along the Kuban-Makla divide and in the upper reaches of the Chegem and Cherek. The flexures have stayed fairly fixed in spcae since the Paleozoic on account of the deep faults bounding the uplift to the east and west. The systems of small faults and flexures now seen are surface expressions of these faults.

The Mesozoic and Cenozoic volcanic areas within the Elbrus volcanic region occur where the transverse flexures meet the larger systems of lengthwise faults. The areas at the eastern margin are the Mesozoic-Cenozoic upper Chegem one (where a flexure meets the faults of the Glavnyy zone and of the zone of depressions), the Cenozoic lower Chegem one (where a flexure meets a fault whose western continuation occurs along the Eshkakon and Malka as a tectonic contact between the Silurian and lower Paleozoic schists), and the Cenozoic Pyatigorsk one (where a flexure meets supposed faults between the Pyatigorsk and Stavropol platforms). At the western margin we have the Mesozoic-Cenozoic Elbrus volcanic area, where the flexure meets the faults of the Glavnyy zone and of the zone of depressions (this is similar to the upper Chegem area).

Analogy with the lower Chegem area would lead us to expect Cenozoic volcanic acitivity in the basin of the Khasaut and Eshkakon (Figure 1); but here the flexure at the western margin is not at all clearly seen at present, and surface signs of Cenozoic activity have not yet been found. They may occur at some depth, though.

These intersecting longitudinal and transverse systems give the Elbrus region somewhat the form of a parallelogram; the corners are the meeting points and correspond roughly with the centers of Mesozoic and Cenozoic volcanic areas, which were active when these systems were being formed (Figure 1). These faults arose and remained active over a long period, which must imply that the parts of the crust moved in various directions along them. The points of intersection are then ones of greatest movement (of greatest tectonic activity); the areas of most vigorous volcanic activity then coincide in time and space with those of greatest tectonic activity. This feature is common to the Mesozoic and Cenozoic volcanic regions

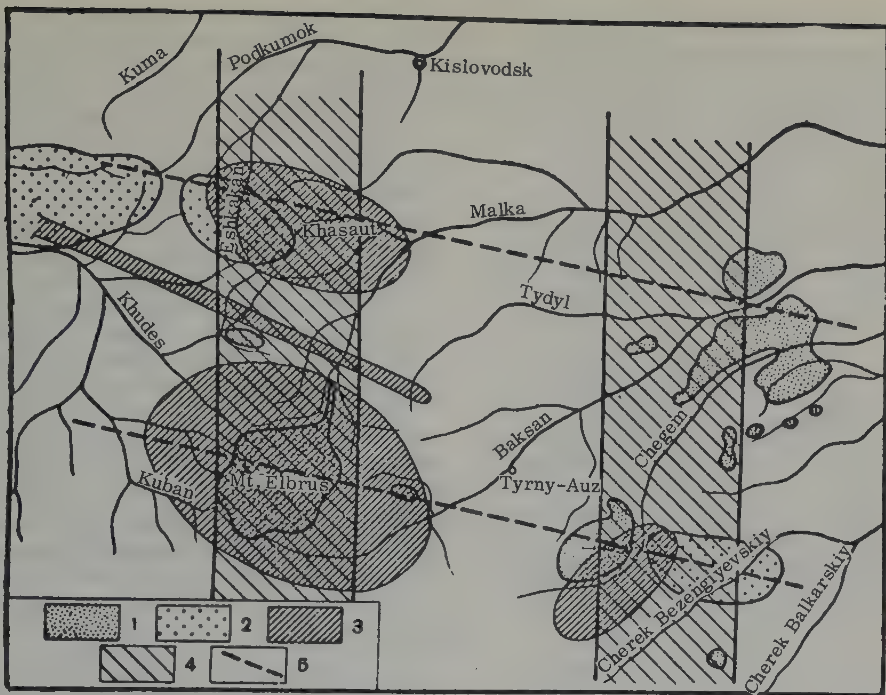

FIGURE 1. Distribution of the volcanic and hydrochemical areas in the Elbrus region

1 - Cenozoic; 2 - Mesozoic volcanic formations; 3 - hydrochemical areas showing high NaCl; 4 - zones of transverse flexures forming the east and west margins of the Elbrus-Stavropol transverse uplift; 5 - approximate positions of the main longitudinal deep fault lines.

throughout the northern Caucasus; it is especially clear along the eastern and western margins of the Elbrus-Stavropol uplift.

These areas of maximal activity are also generally ones showing the most signs of hydrothermal effects; we may say that tectonic processes are correlated in space and time with magmatic and hydrothermal ones.

The largest associations of carbonated mineral springs in the northern Caucasus occur in the regions of greatest activity as defined above. This is especially well seen in the Elbrus region, where there are more than 100 such springs. These are associated with weakened areas of the crust, as is demonstrated by an analysis of the conditions in which these springs occur in regions that have been examined in detail; these weakened parts are either regional faults long present or steeply dipping contacts with magmatic bodies. For example, the large group at Bityuk-Tyube (to the west of Mount Elbrus) forms a chain extending along a fault line in Paleozoic granite and granite-gneiss; on the eastern continuation of this line we find the springs in the upper reaches of the Baksan. The springs of Dzhily Su, Birdzhaly Su, Sultan Gora Su, Islam Chat, Shaukol, and so on are associated with the deep faults in the zone of depressions, in adjacent parts of the Glavnyy Range, and in the zone of lower Paleozoic schist to the north. The springs at Bil'bichan, Ingushli, and Indysh are assigned to a single genetic group not only on the basis of their salt content but also as being associated with a single fault line in the lower Paleozoic schist and in the northern (red) granite of the basin of the Malka and Kuban. The springs on the Kestanta, Kektash, Sakashil, and Kamyk lie around the eastern continuation of the zone of depressions along fault lines that run through the strata in that zone and through the lower Paleozoic schist to the north. Those in the Valley of Springs are associated with fractures of northwest strike; all lie near a deep fault that forms the northern limit of the Elbrus structural framework.

That is, these springs are associated with faults that penetrate deep into the crust or with contacts of igneous rocks; the water must come from great depths, as is shown by the fact that the temperatures at the outlets are always above the mean annual air temperature or the temperature of the neutral layer, in spite of some admixture of water from glaciers. They should

be called thermal springs in Makarenko's [7] terminology. The depth of origin is usually calculated from the geothermal gradient or from Fritz's formula [$T^2 = 1.8(S - 50)$], but no correction is applied for heat lost to the surrounding rocks, so the results are not acceptable even as a first approximation.

The composition of the water is not uniquely related to the composition of the rock complex in which the spring is found. For example, water from the granite of the Glavnyy Range is similar to that from the igneous rocks of Elbrus and to that from the schist of the Valley of Springs, although these rocks differ greatly in composition. Further, we often find waters differing in composition within a single petrographic complex, which must mean that the water is derived from areas outside the complex. The regions of HCO_3-Cl-Na type (Figure 1) in the Elbrus region lie in petrographic complexes ranging from granite to diabase and from clay shale to schist of varying basicity, but there is no important variation in composition; the occurrence and composition are governed by other features.

Thus the position, composition, and temperature all indicate that the waters originated largely in the deeper parts of the crust, as Ogilvie has demonstrated; all the springs are of ascending type. The ascent may be the result of a pressure head (the area of intake lying above that of discharge) or of internal forces (e. g., gas pressure). The geologic section (Figure 2) shows that there can be no artesian basins in the Elbrus region, for the numerous fractures form an open system freely accessible to surface waters; an artesian basin requires a reasonably well-closed system connecting the area of intake to that of discharge. Such a system can exist in sediments if the aquifer is isolated by impermeable strata; fractured crystalline rocks cannot provide these conditions, although we must make exceptions for deep faults and contacts with magmatic bodies, which can form isolated channels. These channels are the ones giving rise to the springs.

These channels might be thought to provide a basis for artesian systems, but then it would be necessary to assume that the channels are connected at great depths, one branch acting as intake for surface water and the other as outlet. It is inherently unlikely that two isolated channels could occur at depth; moreover, the idea is in conflict with known facts. The fault lines on which the channels lie, and all deep faults generally, are nearly vertical; they can meet only at very great depths, where water cannot exist in liquid form. The closed system then could not give rise to a pressure head, so the rising waters of the Elbrus region are not driven by gravitational forces; the processes at work are comparable with upward displacement of hydrothermal products.

Artesian pressure is possible only for those springs that rise in the sediments of the zone of depressions; here the water shows clear signs of interaction with the sediments. In general, pressure heads play only a very minor part in the waters of the Elbrus region.

Most of the mineral springs are thermal (see above as to the temperatures); the temperatures in the Valley of Springs at the surface varied by only 1.5 to 4° between February and July-August in 1958-9, the variations becoming rapidly smaller with depth. The water

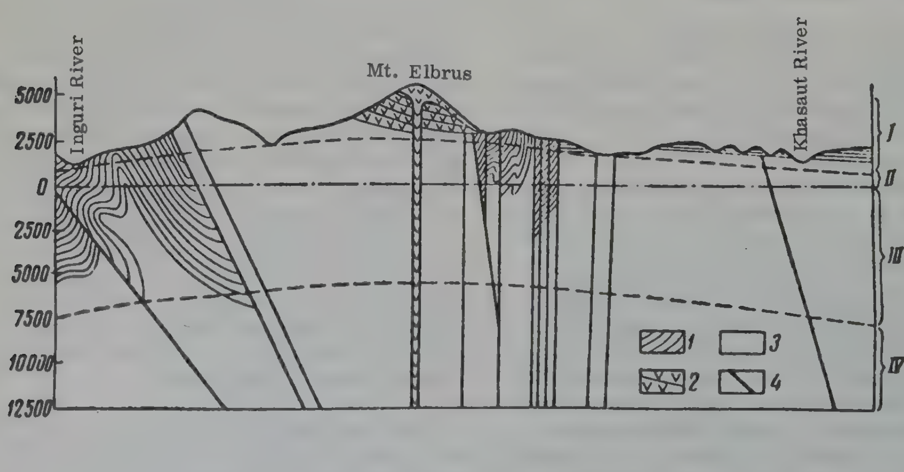

FIGURE 2. Transverse geologic section of Mt. Elbrus

1 - Sediments; 2 - volcanic rocks; 3 - crystalline rocks; 4 - fault lines. Zones: I - dynamic runoff with descending flow towards local erosion features; II - slow runoff with flow towards regional draining surfaces; III - relatively stagnant water (Makarenko); IV - water in vapor state.

temperature is effectively constant, but not all springs have the same temperature; the differences range from 4 to 24° and are affected by many factors, of which admixture of glacial water is important. The highest temperatures occur at the main volcanic center (Elbrus); here the most notable springs are the Dzhyly Su (22.4-24°) and the Bityuk Tyube (18-19), which are closest to glaciers and to the snow line. Figure 3 illustrates the effects of distance from this center; the variation is very pronounced, especially for the first 14 km, which points to increased rock temperatures (higher position of the focus or higher residual temperatures) near that center. The lower curve represents the mean annual temperature of the neutral layer approximately. These two curves illustrate the correlation with distance from the center very well.

There is another center of high temperatures in the Valley of Springs.

The schists vary greatly in composition, but on average they are more basic than the granites; all the same they give rise to an entirely analogous range of compositions (HCO_3 to HCO_3-Cl-Na). The Ca:Mg ratio is 1.5 to 2, although the schists themselves vary greatly in this respect; the proportion of Na is 0 to 80%. The HCO_3-Cl-Na type accounts for somewhat under half of all samples, but these include some of salt content exceptionally high for schist (up to 23 bm/1, as for the Bil'bichan and Ingushli springs).

The Elbrus dacites and andesites do not give rise to many springs; all of these are of HCO_3-Cl-Na type with much Ca and Mg. The ratio of these two rock types varies from 0.7 to 2.6, although the rocks show comparatively little variation in this respect.

For comparison, we give diagrams for the flysch zone of southern Osetia (Ustiyev and

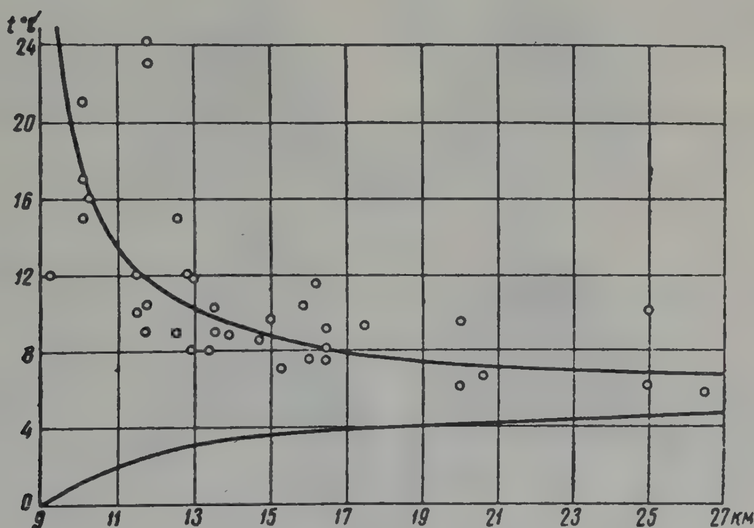

FIGURE 3. Temperature of hot springs as a function of distance from Mt. Elbrus.

Numerous analyses of the water and rocks [1, 2, 10] enable us to discuss the conditions giving rise to the water. Figure 4 shows diagrams for the composition of the water in various petrographic complexes; the following feature is notable. The granites do not vary much in composition, but they give rise to waters very different in composition (from pure bicarbonate to bicarbonate-chloride, with variable proportions of cations). The ratio of Ca to Mg is roughly constant at 1.4, while the ratio for the granites if 0.8; the proportion of sodium varies from 5 to 90%. The commonest type of water is that of HCO_3-Cl-Na type having a total salt content between 1.5 and 4-5 gm/1.

Moleva, 1933); here we find the HCO_3 and HCO_3-Cl-Na types in a variety of clay, sand, marl, and calcareous deposits, the only exceptional feature being the very small proportion of Mg.

That is, waters differing greatly in composition can occur within a single lithologic or petrographic complex, while waters of identical composition can occur in rocks very different in composition. This is particularly well seen for the HCO_3-Cl-Na type, which occurs with only minor variations in composition in granite, schist, andesite-dacite, and flysch. Of course, there are variations between complexes, for the water undoubtedly interacts with the rocks.

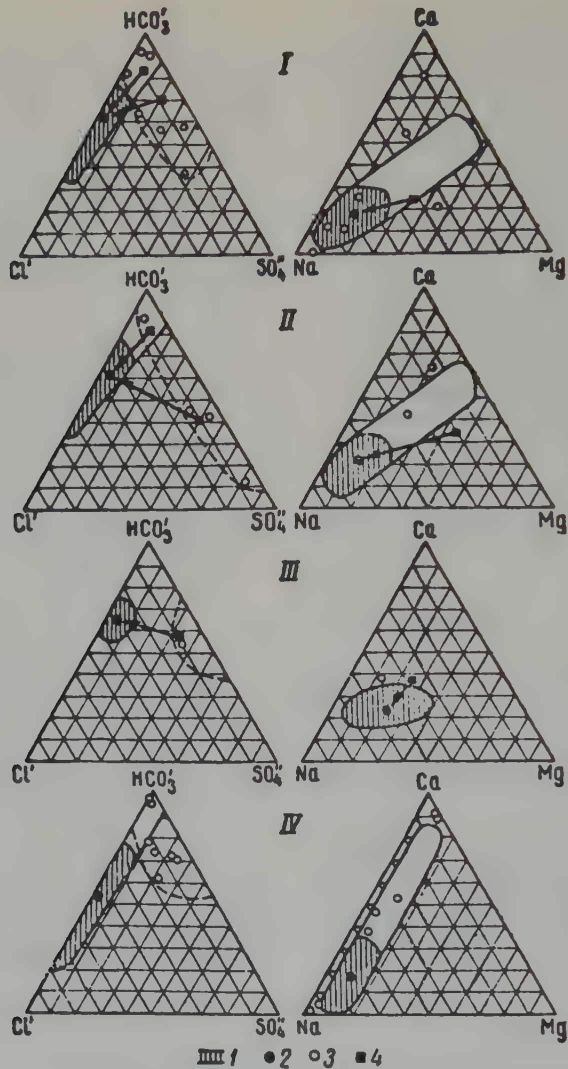

FIGURE 4. Composition diagrams for mineral waters, rocks, and leaching products

Waters: I - in Elbrus granite; II - in Elbrus schist; III - in Elbrus lavas; IV - in flysch zone of southern Osetia. Types: 1 - HCO_3-Cl-Na; 2 - mean for the previous; 3 - leaching products from rocks; 4 - rocks.

This feature indicates in relation to the Elbrus region that the HCO_3-Cl-Na type is largely dependent for its composition on factors external to the region, for the complexes have no great effect on the composition.

The diagrams give some analyses for the various petrographic complexes. The granites lie close to the area of the Na-Ca-Mg type in the cation diagram; there is clearly too little Na for the granites to give the Na type. The anion diagram contains two analyses for granite, one from a region of the HCO_3 type and the other from a region of the HCO_3-SO_4 type. There is too little chloride in the first case, and too little bicarbonate and chloride in the second for the rock to give rise to the HCO_3-Cl type. The average proportions of Na, Ca, and Mg in the andesite-dacite are such as to imply a deficiency of Na; the HCO_3-Cl waters found

here are enriched in HCO_3 and Cl relative to the rock. There are deficiencies of Cl, HCO_3 and Na for schist in relation to the HCO_3-Cl-Na type.

Table 1 gives results from leaching tests on some rocks; analyses of the extracts [4, 12, 13] have been entered in Figure 4. The results for the rocks, extracts, and water samples indicate that the HCO_3-Cl-Na type cannot be produced from these rocks alone; in some cases one can obtain an extract whose cation composition approaches that of the natural water, but then there is always a great deficiency of HCO_3 and (in part) of Cl. The Elbrus region contains no rocks that could give rise to the HCO_3-Cl-Na type so commonly found there; other processes must be responsible for the NaCl and bicarbonate.

The waters of HCO_3-Cl-Na type form three clearly defined hydrochemical areas in the Elbrus volcanic region. The chloride content on the average is 31.6% or 0.49 g/l (Elbrus area itself), 25.5% or 0.60 gm/l (upper Chegem), 33.4% or 0.63 gm/l (Eshkakon-Khasaut area), and 62.2% or 6.08 gm/l (springs along the Bil'bichan-Indysh fault line). All others outside these areas give an average of only 4.8% (0.03 gm/l). These hydrochemical areas of high Cl content coincide precisely with my [8] previously described areas of volcanic and intense tectonic activity.

The Elbrus volcanic area lies in the southwest corner of the Elbrus tectonic framework at the intersection of longitudinal and transverse faults; it shows many signs of Mesozoic and Cenozoic volcanic activity in the surface facies, and it has relatively hot springs rich in chloride and alkalies. There are large areas of travertine, which point to more vigorous hydrothermal activity in the recent past (Wurm stage). There are now many points of emission of dry CO_2, and SO_2 continues to be evolved near the top of the now extinct volcano.

The upper Chegem volcanic area lies in the southeast corner of the tectonic framework; there are many Mesozoic and Cenozoic intrusions, lava flows, and ignimbrites. The springs are few, but these have much chloride. The travertine suggests more vigorous hydrothermal activity in the past (Wurm).

The Eshkakon-Khasaut volcanic area is

Table 1

Leaching Tests on Crystalline Rocks

Rock	Composition of extract	Conditions	Source
Serpentinite, Malka River	$M_{0,25}\dfrac{CO^3_{64}HCO^3_{31}}{Mg_{92}}$	Temperature and pressure normal, water distilled, time one day	N. Caucasus Div. Lab. Hydrogeol. Prob. (S.I. Pokhomov & K. V. Karpova)
Epidiabase, Malka River	$M_{0,14}\dfrac{HCO^3_{55}SO^4_{35}}{Na_{50}Ca_{36}}$	"	"
Amphibole schist, Malka River	$M_{0,25}\dfrac{SO^4_{53}HCO^3_{43}}{Ca_{42}Na_{34}}$	"	"
Sericite schist, Malka River	$M_{0,14}\dfrac{HCO^3_{46}SO^4_{46}}{Na_{51}Ca_{29}}$	"	"
Phyllitic schist Malka River	$M_{0,35}\dfrac{SO^4_{81}}{Ca_{64}Mg_{22}}$	"	Inst. Balneol., Caucasus Hot Springs (V.N. Surkov [12])
Trachyliparite, Mt. Zheleznaya	$M_{2,4}\dfrac{HCO^3_{92}SO^4_{5}}{Ca_{46}Na_{30}Mg_{17}Fe_{7}}$	Temperature +20°, pressure 30 atm CO_2, 18 hr distilled water, rotating autoclave	
Granite, Baksan River	$M_{1,9}\dfrac{HCO^3_{90}}{Ca_{57}Fe_{23}Na_{10}Mg_{10}}$		Lab. Ore Geochem VSEGEI (N.I. Khitarov [13])
Granodiorite	$M\dfrac{HCO^3_{47}CO^3_{37}}{Mg_{46}Na_{33}Ca_{20}}$	Temperature 430 to 460°, 100 to 500 atm 10 hr, rotating autoclave	
Trachyliparite, Caucasus Hot Springs	$M_{0,66}S{:}O^2_{0,22}\dfrac{HSiO^3_{48}HCO^2_{24}CO^3_{19}}{Na_{65}Mg_{13}Ca_{11}}$	"	A.N. Buneyev [4]

Table 2

Mean Chloride Content of Water from Various Tectonic Regions of the North Caucasus

Elbrus volcanic region					
Area	Elbrus volcanic	Upper Chegem volcanic	Eshkakan-Khasaut	Bil'bichan-Indysh fault	All others
No. of springs	30	3	12	4	42
Range gm/l	0.159—1.800 0.49	0.194—0.854 0.60	0.110—1.470 0.63	3.360—7.166 6.08	0.002—0.147 0.03
Equivalent %	31.6	25.5	33.4	62.2	4.8
Total salts	3.0	4.3	3.3	18.0	1.4

S. Osetia

Area	Main overthrust	Schist zone on south side			
		entire zone	Kel volcanic area	Kista and Ksan-Tli faults	All others
No. of springs	10	39	10	14	15
Range gm/l	0.34—6.30 1.61	0—0.306 0.07	0.040—0.306 0.09	0.042—0.296 0.14	0—0.028 0.005
Equivalent %	44.7	5.5	7.2	9.2	1.61
Total salts	5.0	3.2	2.5	3.4	1.7

related to fractures in the northwest corner of the frame; only Mesozoic volcanic activity is evident, but there may be buried Cenozoic intrusions. The numerous springs are faily hot, and most of them are rich in chloride. Travertine is present.

The HCO_3-Cl-Na springs are related to volcanic activity, as is shown by the constant correlation with areas of volcanic activity, with zones of vigorous tectonic movements, and with deep faults in the Elbrus region; moreover, the water cannot possibly have been derived from the country rocks. The increased amounts of bicarbonate and NaCl are products of magmatic processes that are still going on at great depths.

The same picture is found in the Kazbek volcanic region in southern Osetia; the chloride content is always higher for hot springs that lie along faults which extend to great depths (Table 2). The chloride content is especially high (up to 1.64 gm/l) for springs in the principal overthrust zone.

The origin of the salt and gas content of hot springs must be sought by a parallel study of the tectonics and volcanic activity, for the correlation is extremely close.

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North Caucasus Division
Laboratory of Hydrogeologic Problems
Academy of Sciences of the U. S. S. R.
Stavropol

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GEOLOGICAL STRUCTURE OF THE ULAKHAN-SIS RANGE[1]

by

K. V. Yablokov and I. Ya. Nekrasov

The Ulakhan-Sis Range forms a low ridge of latitudinal trend between the lower reaches of the Indigirka in the west and the Alazeya in the east. There are only scanty and conflicting geographic and geologic information on this region before 1945; a systematic study is at present in hand in the Yakutsk Geological Commission, but the region around this range still remains the least studied in the northeast of the U. S. S. R.

Here we present some results on the geologic structure of the region and the conditions around the Ulakhan-Sis intrusion; these are derived from our own field observations of 1959 and from the available geological surveys.

The range is the eastern part of the Polousnyy marginal folded uplift at the northern edge of the central Kolyma massif [6]; directly adjacent to the north lies the Polousnyy synclinorium of the Verkhoyansk-Chukota folded region [4]. The structure includes Paleozoic and Mesozoic formation, which are cut through by intrusions and lava flows of various ages. The middle Paleozoic is represented by strata of the Upper Silurian to Lower Devonian, which are dated from the fossils but which have not been differentiated (older rocks are not known in this area). Krug and Barankevich state that these are massive gray or dark gray (rarely black) limestones containing Atrypa ex gr. aspera Schloth, which are massive and have thin bedding; the bottom of the section contains calcareous clay shales, some carbonaceous. The visible thickness is about 500 m.

On this series there lies conformably what may well be a Middle Devonian formation consisting of massive light-gray limestones gradually grading upwards into gray and dark-gray thinly bedded limestones containing Stropheodonta sp., Atrypa ex gr. reticularis Linn., A. tubaecostata Paeckelmann, Gastropoda sp., Rugosa, and Pholidophyllum sp. The Devonian strata are up to 400 m thick. The boundary between the formation and the series is drawn arbitrarily along the horizon of light-gray limestones.

The middle Paleozoic strata form a narrow belt parallel to the crest of the range on the southern side (Figure 1). The middle Paleozoic is always unambiguously traceable, but there is much less basis for the stratigraphy of the higher strata, which consist of bands of calcareous sandstone, clayey shale, and limestone; in the upper parts of the section there are bands of porphyritic diorite, spilite, and tuff, ranging from 0. 5 to 20 m wide. The total thickness ranges from 200 to 400 m. These extend in a narrow belt along the northern side of the range; in the west and central parts they are almost everywhere separated from the Devonian strata by an intrusive massif, and only in the east are there fairly extensive direct contacts.

There are disagreements as to the relation of these strata to the Devonian; the majority follow Krug and consider that they lie conformably on the Devonian limestones, but Shangin points out that the folding of the middle Paleozoic differs in direction from that in these strata, on which basis he deduces that there is a gap and an angular unconformity between them. Barankevich also remarks on the differences in the extent of the folding, but he does not mention any unconformity.

Krug made the first age determination on these strata in 1945 when he collected some poorly preserved upper Paleozoic brachiopods. On this basis the strata are assigned to the Permian on the latest general (1:2, 500, 000) geologic maps of the U. S. S. R. [3], edited by Nalivkin. Here a personal communication from E. M. Shesterenkin is of interest (he made a survey of the eastern part of this range in the summer of 1959). In the lower parts of the strata in the basin of the Naan Chan (assigned to the upper Paleozoic) he found conglomerates which meet the Devonian limestones in an angular unconformity. This unconformity is also clearly visible on aerial photographs. He

[1] O geologicheskom stroenii khrebta Ulakhan-Sis, (pp. 58-65).

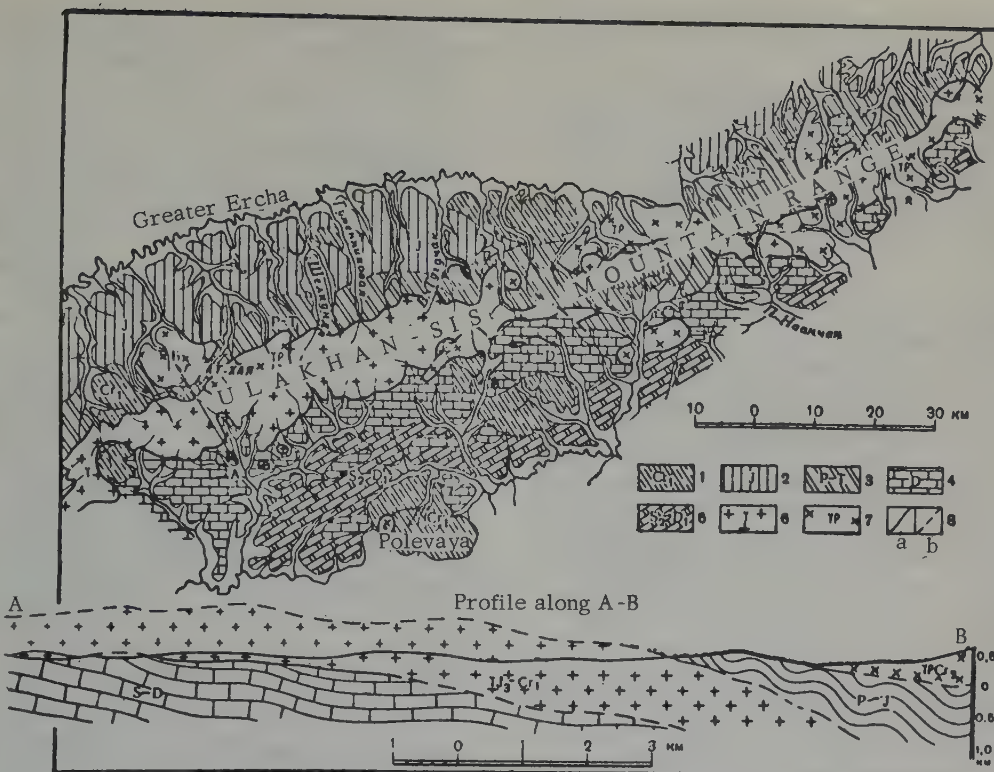

FIGURE 1. Schematic geologic map of the Ulakhan-Sis Range.

1 - Effusive rocks of the Lower Cretaceous (liparite, dacite, andesite, rarely basalt); 2 - Terrigenous rocks of the Jurassic (shale and sandstone); 3 - Terrigenous rocks of the Permo-Triassic (calcareous sandstone and shale); 4 - Devonian limestone; 5 - Upper Silurian - Lower Devonian limestone; 6 - Medium-grained biotite granite of the Upper Jurassic - Lower Cretaceous; 7 - Biotite-amphibole granodiorite and monzonite of Cretaceous age; 8 - Geologic boundaries: a-established, b-assumed.

collected pelecypods of the genus Kolymia sp. from beds directly above the conglomerate; these define the age of the sedimentary formations as Upper Permian. Significantly, these results cast much light on the lower boundary and age of the strata previously assigned to the Premian.

The upper age limit is much more difficult to determine, for no fossils have been found in the upper parts of the complex. Specimens we collected for spore and pollen analysis have yielded only very much deformed and disintegrated connective tissue, which cannot be identified. Further search can hardly be expected to yield good paleontologic material, for the upper parts of the complex have been largely converted to hornstone over much of the area. Relationships to higher formations, whose ages must be determined, will form the only way of dating the strata above the beds bearing Kolymia sp. These higher formations consist of alternating sandstone and shale, usually dark, but with some bands of green, gray, brown, or mottled sandstone; there are also rare thin lenses of pebble conglomerate. The individual bands range in thickness from a few centimeters to 5 m. The composition of the section becomes more homogeneous upwards, and clay shales begin to become dominant.

The direct field observations relate only to the bottom 400 to 600 m of the strata; the total thickness would appear to be as much as 5000 m [7].

Krug and other early workers in the area assigned the terrigenous beds on the northern slopes of the range and in the basin of the Ercha to the Upper Jurassic, by analogy with Upper Jurassic formations in the central and southern parts of the Polousnyy Range. In fact, the beds on the north of these two ranges belong to a single structure (the Polusnyy synclinorium). extending as a broad belt along the northern boundary of the Kolyma central massif and consisting of homogeneous terrigenous beds of the Verkhoyansk complex, a series of beds

continuous from the Permian to the Upper Jurassic, inclusive.

Only certain Upper Jurassic beds were distinguished in the early studies on the Verkhoyansk complex in the northern part of the western end of the Polousnyy Range (the region used in Krug's comparisons). Studies by Burov, Cheremisina, and others in 1958-9 confirmed the stratigraphic scheme that had been proposed for this synclinorium [7]; finds of fossil fauna demonstrated clearly that the beds previously assigned to the Upper Jurassic in fact contain ones belonging to the Upper Triassic and to all parts of the Jurassic. If we accept Krug's analogy, the terrigenous beds on the north side of the Ulakhan-Sis Range become Upper Triassic and Jurassic. G.I. Mikheyev (personal communication) states that the fossils found in 1959 in the presumed Upper Jurassic beds along the right bank of the Ercha in fact are derived from all parts of the Jurassic. This means that the eroded surface of the Devonian limestone is in contact with beds having Upper Permian fossils at the base and having Triassic and Jurassic layers higher up.

There are various views on the relation of the Mesozoic to the upper Paleozoic; the majority follow Krug in believing that the boundary between the Permian and the terrigenous Mesozoic sequence lies along a fault, but Leksikova, who worked on the Ulakhan-Sis Range in 1948, found no trace of this; she considered that there is merely an unconformity. The facts available do not suffice to decide the question. The contact runs through swampy wooded tundra, with few exposures along river valleys. We have performed traverses across the strike of the terrigenous complex in the valley of the Upper Tuguchak and in the upper reaches of the Shelkunda and Gumennikova; these traverses extend from the upper Paleozoic at the contact with the Ulakhan-Sis intrusion to the strata formerly assigned to the Upper Jurassic. The sediments in the lower part of the section are sandstone and shale, much altered; there are also thin bands of igneous rocks and dark limestone. Upper Permian pelecypods have been found in the lower parts of this formation at the eastern end; clay shale begins to become dominant towards the top. The bands of limestone and igneous rocks gradually become rarer and vanish completely around the confluence of the right and left branches of the Upper Tuguckak. Above this there lies an unusual series consisting of 60 to 80% clay shale and mudstone having thin bands of fine-grained carbonate-impregnated sandstone ranging in thickness from 0. 2 to 5 m. Previous evidence would indicate that this series is Upper Jurassic.

There is a similar gradual transition from the Upper Permian to the Jurassic east of the Ulakhan-Sis Range (Shesterenkin observed this in 1959). The strata formerly considered as upper Paleozoic are in fact Upper Permian to Triassic, while Jurassic strata show signs of all three divisions (Burov and Cheremisina).

It would seem that the part of the Polousnyy synclinorium in the Ulakhan-Sis Range consists of terrigenous strata continuous from the Upper Permian to the Upper Jurassic. This abolishes the need for any fault to separate the upper Paleozoic from the Jurassic, which was formerly necessary in order to explain the apparent absence of the lower Mesozoic.

The main tectonic structures in the area are the Polousnyy marginal uplift of the Kolyma central massif and the adjacent Polousnyy synclinorium. The axes of both are parallel and of sublatitudinal strike. The flanks of the uplift (which, as a whole, is an anticline) are cut up by small brachyfolds, which are evident from exposures of the Devonian among older formations. The axes of these run parallel to the strike of the uplift; their widths range from 2 to 5 km, and their flanks dip at angles between 10 and 45° (rarely 60°). The folding becomes less prominent to the east, where wider and more rounded structures are prominent.

The southern flank of the synclinorium is directly adjacent to the uplift and is also cut up by small, often asymmetric, folds running parallel to the main axis. These small structures are themselves dissected by steeps folds a few meters across and by numerous minor faults of tectonic origin.

The disjunctive faults fall into two groups, one of mainly latitudinal strike and the other of meridional, NE, and NW strike. There is a certain spatial regularity in the location of those of the first groups; steeply dipping broad fault lines often 1 km long and 10 to 15 m wide are dominant in the limestones at the center of the uplift. The fault lines are filled with brecciated limestone cemented by calcite. No appreciable displacement along this fault has ever been reported. Again, bedding-plane faults predominate in the Permian and Triassic terrigenous strata in the upper part of the northern flank of the anticlinorium; these are especially prominent at boundaries between rocks of different kinds (limestone with shale, sandstone with shale, and so on). Movement along these lines usually produced much frictional heating, tectonic breccias being much rarer. The movements at boundaries between rocks of differing kinds has often caused the harder rock to break up into lenses; the effect is well seen in exposures in the upper reaches of the Gumennikova (a left tributary of the Ercha). These bedding-plane movements in the synclinorium have produced disharmonic folding and additional buckling in beds of mainly clay content. The clayey shales have been thrown up into complex folds; the

bands of sandstone have been broken up, and the parts are displaced 1 to 5 m. The faulting commonly extends beyond the more brittle rock and along the boundaries between the different rocks. Slip zones are prominent, together with tectonic breccia and so on. Unfortunately, this breccia may be taken as indicating major faults if the exposures are small, although in the vertical direction they do not extend beyond the flanks of the secondary folds.

In general, the center of the marginal uplift has typically broad fault lines; bedding-plane displacements are the main feature near the junction with the synclinorium, while disharmonic folds with other additional folding are the main feature in the southern margin of the synclinorium.

The relation of these structures to the main morphologic elements is such as to indicate that they developed during the folding. The Verkhoyansk complex is extensively folded and is covered by Upper Cretaceous formations with undisturbed bedding. This indicates that the folding is of Late Jurassic to Lower Cretaceous age.

The faults of the second group are clearly later than the folding; they cut through the folds and through the granites of the Ulakhan-Sis massif. They consist of broad fracture zones that can be traced for several kilometers; one such zone lies in the upper reaches of the right Upper Tuguchek. This zone is up to 150 m wide and appears clearly in the relief as a depressed trough of NE strike. It is composed of skarn (from limestone) and contains many quartz veins (thickness up to 0. 3 m). Along the NE edge of the zone there is a thick band of monzonite, which has altered the middle Paleozoic limestones to skarns of pyroxene, garnet, and pyroxene-garnet types. The rocks were displaced vertically several hundred meters after the skarns had been formed. The new weakened zone gave rise to dikes of porphyrites and quartz porphyries, which are probably the roots of Cretaceous flows in the region of the fault.

This description shows that there is a radical difference between the faults associated with the folding of Upper Jurassic to Lower Cretaceous age and the faults of Cretaceous age; the first are local and do not extend to any great depth, whereas the second acted as channels for intrusions and lava flows after the stage of folding.

The Ulakhan-Sis Range contains many igneous formation, which are of three distinct ages. The oldest lie along the axis and consist of bands of limestone, sandstone, and calcareous shale, of the upper Paleozoic; they are diorite porphyries, spilites, and in places liparite-dacites and tuffs. These are a result of the formation of a weakened zone along the northern margin of the central Kolyma massif at the end of the Paleozoic. The next oldest are the various granitoids that make up the large Ulakhan-Sis intrusion, which is of Late Jurassic to Early Cretaceous age. The youngest are various volcanic formations, which include rocks ranging from liparite and dacite to basalt as well as subvolcanic intrusions of diorite porphyrites, quartz porphyries, and monzonites; these are of Late Cretaceous age.

We shall not deal with the petrography and ages of these formations, and will merely present some new arguments on the morphology and origin of the Ulakhan-Sis massif. The granitoids in this massif have an area of about 1200 km^2; the massif extends sublatitudinally for about 180 km between the Indigirka and the Alazeya. Its width ranges from 15 km in the west and center to 3 to 5 km in the east. The northern line of contact is very tortuous; granite tongues run far to the north along the valleys of rivers flowing from south to north, and the country rocks give way to granite along the divides. The plane of contact is well seen in the field, and direct measurements show that its dip ranges from 3 to 15°. This very slight dip has resulted in a belt 3 to 5 km wide of intense contact metamorphism; the country rocks consist of altered shale, hornstone, and (less often) skarn. Erosion has not been very extensive, and relicts of the overlying rocks (hornstone) are found at very many points in depressions, even in the central (highest) parts of the range.

The southern contact is very different; the valleys of rivers flowing from north to south usually reveal slightly altered Paleozoic limestone, tongues of which extend into the granite. The granite penetrates the country rocks along the divides (Figure 1). This type of contact can occur only when erosion reveals the lying side of an almost horizontal sill. There are no root exposures, so the dip of the contact cannot be measured directly, but a contoured map showing the margins of the granite indicates that the dip is 5 to 10°.

Small exposures of granite occur around the contact zone in raised parts of the divide. The contacts here are almost horizontal, as Kondratyev observed in 1949; he found sheet intrusions among small granite bodies near the contacts of this intrusion. Detailed profiles of these bodies indicate that the boundaries lie at the level of the boundaries of the massif, so we assume that these bodies are the remains of eroded parts of the intrusion.

We draw the following conclusions from our own observations and from maps of the range compiled by Shangin, Barankevich, Vlasov, Shesterkin, and others. The intrusion has been described [4] as resembling a batholith, whereas

in fact it is better termed a harpolith [1] whose root may lie in the zone of weakness along the margin of the central Kolyma massif. This zone appears to have been produced as a series of plutonic faults at the end of the Paleozoic, which were responsible for lowering the edge of the massif and for the Polousnyy synclinorium. The terrigenous (Verkhoyansk) deposits filled the resulting depression and concealed these faults in the Paleozoic strata under a layer 3 to 5 km thick. The subsequent minor movements on these faults did not produce disjunctive faulting in the Verkhoyansk complex, though folding did occur.

Tectonic movements at the end of the Jurassic produced complicated folding in the Verkhoyansk complex and were associated with magmatic activity. The granite magma rose along the deep fault produced at the end of the Paleozoic at the edge of the Kolyma massif; it then flowed along the line of least resistance at the unconformity between the rocks of the middle Paleozoic and Upper Permian to form a thick sill between sedimentary-rock beds.

Recent erosion has exposed the granites in the Ulakhan-Sis Range, but the root parts in the north have not yet been so exposed; here we find the upper margin of the intrusion. The granites have been eroded away completely in the south, but this occurred not long ago, for outliers remain, together with the underlying altered rocks. The shape of the zone of contact-altered rocks in the south is significant here; areas of sharn are common several kilometers from the margin, so the granites were finally eroded away only recently.

Granite bodies of this kind are not rare; they have been reported in W. Europe [2], and Azhgirey [1] discusses several in the Altai and North Caucasus. Koptev-Dvornikov [6] states that they are common in Central Kazakhstan.

We believe that the Ulakhan-Sis massif is not unique in the Verkhoyansk-Chukota folded zone; there may be many others to be discovered among the granite massifs of the northeast U. S. S. R.

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Institute of the Geology of Mineral Deposits,
Petrography, Mineralogy, and Geochemistry,
Academy of Sciences of the U. S. S. R.,
and Yakutsk Branch,
Siberian Division,
Academy of Sciences of the U. S. S. R.

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MAIN BOUNDARIES AND GEOLOGIC STRUCTURE OF THE UPPER AMU DAR'YA DEPRESSION[1]

by

N. P. Tuayev

The boundaries of the depression are defined more precisely than heretofore, and the depression is renamed the upper Amu Dar'ya depression; four uplift zones and three downwarp zones are distinguished. It is concluded that the depression is not a linear folded zone of geosynclinal type but a massif that has been split into large blocks by broad belts of faults, which are seen in the uplift zones.

The region is considered to be a southeastern deformed extension of the Kara Kum platform that has been subjected to major structural alteration.

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1. BOUNDARIES OF THE UPPER AMU DAR'YA DEPRESSION

The boundaries and shape of this basin, especially of that part in Soviet territory, were considered at an earlier stage in the study of the geology of Asia; the views then taken were in accordance with the geologic evidence available at that time, but hey have since been gradually modified as new material has accumulated.

The beginning of this study was in the 1930's; the extensive geologic studies of the time within the Soviet part of the depression revealed a correlation between relief and structure and paleographic features. A considerable time has now elapsed since the start of these studies, and much geologic, geophysical, and borehole information has become available for the adjacent regions of Uzbekistan and Turkmenia.

The new material enables us to revise previous ideas, for it casts much light on the main lines of the structure. I shall rely as regards the structure of the part in Afghanistan on published sources and also on deductions pertaining to the history of the depression as a whole, especially the relation of relief to tectonics; these deductions have been drawn from the morphologic and tectonic sequence in the Soviet part.

The relief is so clearly related to structure that geomorphic analysis gives results in full agreement with deductions made on other grounds [22] as to the structure of the Afghanistan part. This analysis enables us to identify the margins of the depression (a first order negative structure) as first order positive structure; the margins so established in the south and southeast agree with Furon's [17] results, as well as with Popol and Tromp's.

The ranges of the Paropamisus (3709 m), Koh-i-Baba (over 5000 m), and Hindu Kush (7700 m in the Tiraj Mir) form the southern boundary; the ranges of Pamir form the eastern one, where the western ranges extend up to about 7000 m. The northern boundary runs along the Gissar Range (height about 5000 m), and the southwestern boundary is not represented in the relief. The northwestern boundary runs along the Kugitang Tau, Baysun Tau, and Surkhan Tau, which range up to about 3500 m. The inner low part extends along the Amu Dar'ya in a sublatitudinal direction, and submeridionally along the Surkhan Dar'ya; it is a level zone of near desert. The plain lies at about 500 m in the east and 270 m in the west.

The depression as a whole takes the form of an oval cup with a broken southwestern edge; we shall see that the margin here has a highly dissected surface, which is a result of the structure. The margins show a sequence of depressed zones (long valleys and round depressions) and elevated parts (oval raised areas and extensive ranges). The positive forms corespond to anticlinal structures; the negative, to synclinal ones. Some of these elements have direct continuations in Afghanistan.

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[1]Verkhne-Amudar'inskaya vpadina, yee granitsy i osnovnyye cherty geologicheskovo stroeniya, (pp. 66-75).

The general heights above the inner part of the depression range from 1000 m in the Tuyun Tau to 2967 m in the Kugitang Tau for the Soviet part, and from 1250 m (Koh-i-Elburz) to 2000 m (Koh-i-Shadian) in Afghansitan. The maximum heights of the boundaries above the inner zone range from 3500 to 7000 m, the lowest values at the western margin. The depression has an area of 375 x 325 (121,875) km^2 and is elongated in a sublatitudinal direction.

The structure presently understood is best reviewed by reference to the history of the subject. In the early 1930s Klebelsberg [21] distinguished the marginal part of the Pamir system (which consists of Cretaceous and Tertiary strata) as a special zone. This zone he defined in terms of Paleozoic metamorphic rocks on three sides only (east, north, and, in part, west); the southern side was left open. Later, Kheraskov [16] described this zone as a region of downwarping, for which he proposed the name Tadjikistan depression. His tectonic map shows that as bounded on the west and northwest by the ranges of the Surkhan Rau, Baysun Tau, Ketimen Chapta, and Kugitang Tau, on the east by the western side of the Darvaz, on the north by the southern side of the Gissar Range, and on the south by the Amu Dar'ya (the boundary between the U. S. S. R. and Afghanistan). Areas to the west of the Kugitang Tau he described as the outlying parts of the Gissar system. This scheme left the southern boundary open, as did Klebelsberg's.

Later Burachek [1] used paleographic analysis to deduce the age of the depression and margins; he proposed to call it the south Tadjik depression. He believed that the Paleogene sea was surrounded on the north and east by a semicircle of isolated areas of land, which stood on the sites of the Gissar and Darvaz ranges. He considered that the western side of Kabulistan formed the southern shore of this sea.

I have demonstrated [10, 11] that the current relief in the north is governed solely by tectonic features; morphologic and tectonic classification indicates [12] that the southern oil-bearing region (south Tadjik depression) is "not an independent province in terms of geologic structures or geomorphology; it is simply part of the large Amu Dar'ya depression". The southern margin is formed by the ranges of the Paropamisus and Hindu Kush; the eastern, by the west side of the Pamir; and the northern, by the Gissar Range (including its extension to the southwest). The western part differs from the other margins in being one of gradual transition, which acts, as it were, as a lip pointing west. I [11] proposed a new name (the Amu Dar'ya depression) for the Tadjikistan depression in the light of fresh knowledge; this depression began to form in Mesozoic time as a tectonic element that had its most pronounced expression between the Tertiary and Quaternary, or perhaps in part during the Quaternary. The geomorphology, hydrographic features, and position of the Quaternary strata led me to deduce that the position relative to the surrounding ranges and the radial form of the drainage network are the results of very recent downward movement. I also deduced that the relief is of a structural type and is controlled as a whole by the geologic structure, and that the uplifting of the peripheral zones was uneven. This last I used in order to explain the migration of the Amu Dar'ya to the north and the loss of the tributaries rising in the Hindu Kush.

Burachek and I have used geomorphologic, paleotectonic, and paleographic features to distinguish the Tadjikistan depression as a separate part of Asia; Petrushevskiy [6] has done the same. In this way we have been able to obtain a clearer picture of the depression and to demonstrate its independent existence subsequent to the Cretaceous.

There are reasonably numerous papers [1-4, 7, 9-12] on the Paleogene in the northern and eastern margins, but the situation at the southern margin is not so satisfactory. Little work has been done on the structure of northern Afghanistan, and we cannot distinguish the exact southern limit of the Paleogene strata, which serves as the southern boundary of the upper Amu Dar'ya depression. The geologic literature on the Paleogene of the northern parts of the Hindu Kush and Paropamisus relates only to isolated areas, but our evidence can be supplemented by reference to exposures of the Tertiary in northern Afghanistan which lie near the border and can be observed from the right bank of the Amu Dar'ya. The most important exposures of the Paleogene lie in the Shamar anticline, which lies on the structural line joining the Koyki Tau and Tuyun Tau; these three anticlines have crests composed of Paleogene limstones, while the edges reveal the higher levels of the Paleogene and the Neogene. The Shamar anticline forms a prominent ridge about 200 m above the surrounding country; it has a southeast strike. As far as one can see by eye from the right bank of the Amu Dar'ya, adjacent ridges to the east have the same strike.

Gizancourt [20] states that Paleogene strata are known in the northern parts of the Hindu Kush around the Koh-i-Ambar, Ali-Abad, Tashkurgan, and Shibirgan ranges (from east to west). Paleogene strata have been reported at a number of places further west; e. g., at Shibogla Páss, between Kala Durband and Daban-i-Kushan, and between Bala Murgabom and Kala-i-Nau [20]. Griesbach [19] states that the Nummulitic series (Paleogene) occurs near Kushk at Khodja Kalander (with Ostrea multicosta Desh var. and O. turkestanensis Rom.); further, limestones in the oil-bearing Angot region, which previously were assigned to the

Turonian, are [15] analogous to the Bukhara stage (Lower Paleogene) of Central Asia.

These observations indicate that Paleogene strata occur almost everywhere along the northern side of the Hindu Kush and Paropamisus. Furon [17] indicates that the Nummilitic series joins up with the Paleogene of the Afghan and Iranian Khorasan in the west; Griesbach [18, 19] and Vredenburg [28] find that the Paleogene strata gradually become of flysch type further south, where they grade into the thick Cretaceous flysch on the southern side of the Hindu Kush. On this basis I feel justified in drawing the southern boundary of the depression along the northern sides of the Hindu Kush and Paropamisus ranges (Figure 1).

The southwestern boundary cannot be defined so clearly, for it does not appear in the relief, but the paleotectonics and apleography of the Tertiary show [10, 11] that movements of opposite sign in the internal and peripheral parts have produced three brief periods of separation from adjacent regions.

Griesbach [18], Popol and Tromp have described considerable magmatic activity in the Late Cretaceous in the western extension of the Bend-i-Turkestan and Paropamisus; this recurred from time to time into the Neogene. The most recent hydrothermal phase would appear to have been responsible for the vein mineralization in the Kugitang Tau and adjacent regions, as well as for the mineral and thermal springs that have been discovered in boreholes in Dzhayrankhan and that occur throughout the upper Amu Dar'ya depression. Ognev [5] and Smirnov [8] have found sills of andesite and basalt in the middle Paleogene in southeast Turkmenia around Badkhyz, which lies on the Bend-i-Turkestan structure lines. At Khau Dag (borehole 136) they found basalt dikes at 985-1218 m in Turonian beds; these must be post-Turonian.

This is a general outline of the evidence on the southern and southwestern margins of the depression. The relief is related to the structure, so we may say that the structural zones of southern Tadjikistan and Uzbekistan extend into northern Afghanistan; this confirms Burachek's and Petrushevskiy's views on the northern parts of the Hindu Kush and Paropamisus as the southern margin, although the part of Afghanistan north of those ranges has been called the northern Afghanistan depression. Kherashov's Tadjikistan depression should be considered merely the northern part of an enormous depression, whose parts have been given various names. The northern part has been called the Tadjikistan depression, the southern Tadjikistan depression, and the Amu Dar'ya depression; the southern part (between the Amu Dar'ya and the Hindu Kush, and so on) has been called (by Smirnov and others) the northern Afghanistan depression. The Tadjukistan and northern Afghanistan depressions are really only halves of a single depression covering southern Uzbekistan, Tadjukistan, and northern Afghanistan, so the old names are unsuitable. My previous proposal (the Amu Dar'ya depression) is also unsuitable, for other depressions that have been given the same name have now been described for the lower parts of the Amu Dar'ya.

The best name would appear to be the upper Amu Dar'ya depression; the northern part may be called the foothills of the Gissar range, while the northern Afghanistan part may be called the foothills of the Hindu Kush and Paropamisus.

The Lower Quaternary beds in the Gissar foothills dip at angles up to 35° and are up to 400 m thick; this would indicate that the localized depressions were produced in the Quaternary.

2. MAIN FEATURES OF THE STRUCTURE OF THE DEPRESSION

The depression is a first order structure, which [13, 14] is a continuation of the southeast of the Kara Kum platform and which is bounded on the north by the Pamir-Gissar system and on the south by the Hindu Kush and Paropamisus. The platform has been converted to an enormous depression in recent times; this has given it the special tectonic features described briefly below.

The literature indicates that the Mesozoic and Cenozoic in the Afghanistan part is analogous to the same in the Soviet part. The middle region of the depression differs from the margins in that it is made up almost solely of Quaternary rocks, which comprise a plain about 80 km wide around the Amu Dar'ya (there are also branches along the Surkhan Dar'ya and elsewhere). The stratigraphy of the Mesozoic-Cenozoic beds varies very little, but the edges of the depression differ greatly in structure. The Gissar foothills have submeridional folds of north to northeast strike, which curve somewhat to the northwest; this strike persists right up to the southern side of the Gissar Range, where it changes to northeast and becomes almost the strike of the Gissar Range. This sublatitudinal strike is most prominent in the northeastern part of the depression; further east, in the Alai corridor, which joins the present depression to the Tarim depression, we find the Mesozoic and Cenozoic beds thrown into folds of latitudinal strike. That is, the more recent structures show a strike very much adapted to the Paleozoic sturctures. The northern margin may be divided into several large raised and lowered zones, which themselves contain folds of smaller scale (some complex) and disjunctive faults. The tectonic movements persisted into the Quaternary, and commonly we find

Cretaceous beds thrust upon Lower Quaternary ones (Kulyab formation), which are in places thrown into folds whose flanks dip at angles up to 35°.

Kheraskov distinguishes the following zones from east to west: the Kulyab depressed zone, the Vakhsh uplift, the Kurgan-Tyube depressed zone, the Surkhan depressed zone, and the Kugitang uplift. Figure 1 shows that most of these are directly related to structural zones at the southern margin reported by Popol and Tromp [22], who distinguish three systems of folds. The first of these occurs in the Andkhoy-Daulatobad region and is seen as the Dasht-i-Kasym uplands (at L. Khodja Mohammed Khan), which lie in the northwest part of the southern margin and have a northeast strike. The second forms the middle and consists of a set of folds having a latitudinal strike between the Paropamisus in the south and the forward ranges of Koh-i-Elburz, Koh-i-Shadian, and Khodja Gut to the north. The third lies to the east and consists of numerous fairly small folds striking northwest.

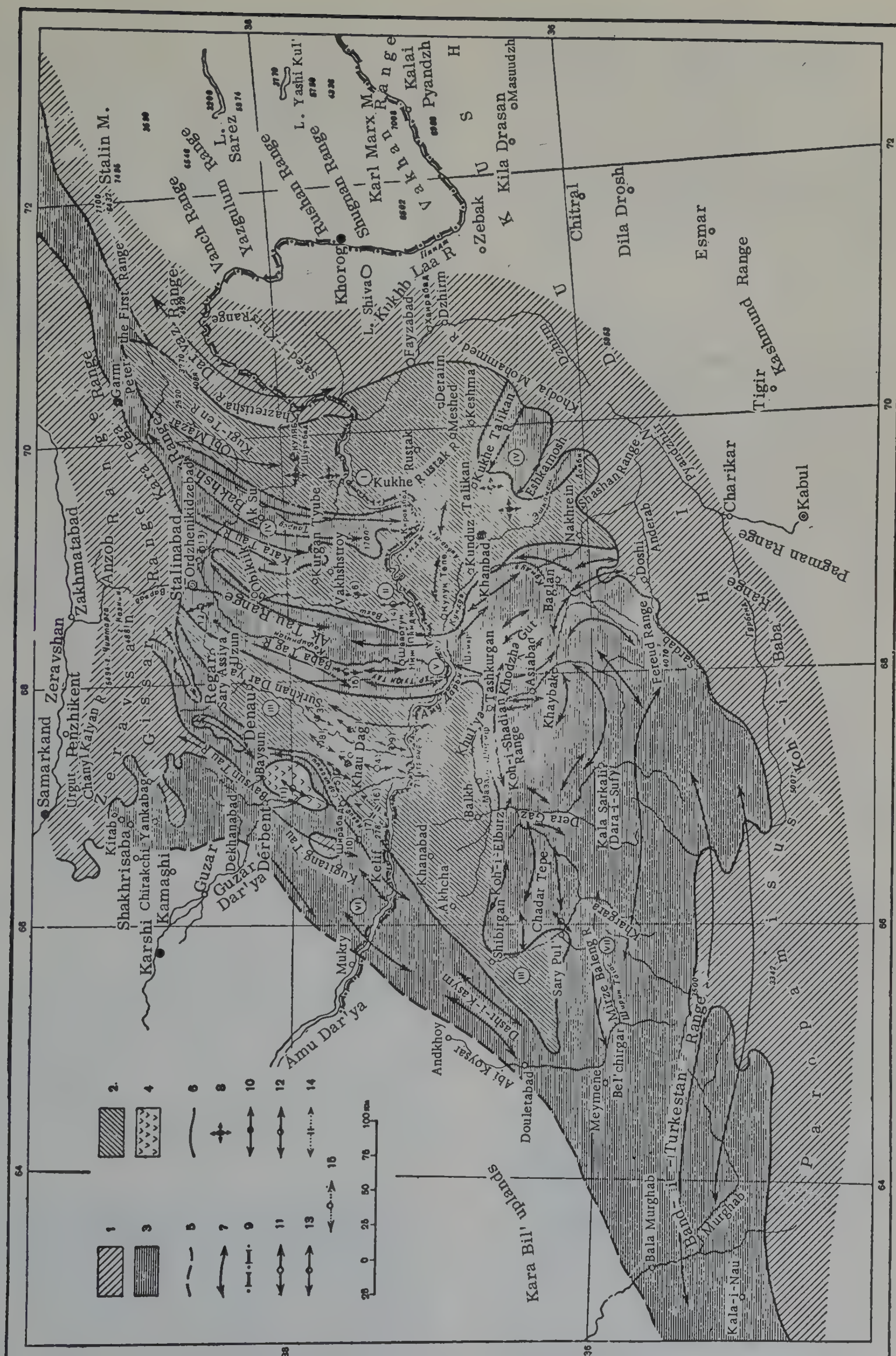
These systems I equate with uplift zones and name them (from west to east) the Andkhoy, Koh-i-Elburz with Paropamisus, and Khaybak-Kunduz. There are also prominent depresssed zones, namely the Balkha to the west and the Khanabad and Rustak to the east (Figure 1).

Popol and Tromp describe systems of folds within these zones, and these systems contain various types of structures, some of them of them of very small extent. The Andkhoy zone contains two systems, namely the Khodja-Makhamedkhan-Mukra (west) and Kelif (east), both of which are of northeast strike. The first of these appears in the relief to the south between Andkhoy and Daulotabad, where it consists of Quaternary rocks, while in the north (around Mukra) one can see from the right bank of the Amu Dar'ya that peaks of Cretaceous and Tertiary rocks stand out among Quaternary ones. The second is a direct continuation of the Shirabad-Kelif Ridge [9] on the Afghanistan side of the Amu Dar'ya; this ridge is well seen from the Soviet side and consists of a group of structures composed of rocks of Albian to Paleocene age. This group is the connecting link between the Andkhoy and Kugitang zones; the two zones are really one, which may be called the Andkhoy-Kugitang-Surkhan Tau zone.

Popol and Tromp state that the Koh-i-Elburz to Paropamisus zone has a very complex structure. Three large anticline subzones occur in the southern part (the Paropamisus, Bend-i-Turkestan, and Dara-i-Suf or Dori Su), as well as three smaller ones (the Mirzavala to Koh-i-Shiran one (Bogavis), the Chadartepi one, and the Koh-i-Elburz one). These subzones have undulating axes and are split up into separate

FIGURE 1. Schematic map of the morphologic structure of the upper Amu Dar'ya depression (Tuayev, 1959).

1 - Surrounding areas (Paleozoic to the N and E, metamorphic to the SE and S, the latter including rocks from Precambrian to Cretaceous); 2 - depressed zones (numbers on map): I - Kulyab-Rustak; II - Kurgan-Tyuba-Khanabad; III - Surkhan-Balkh; 3 - uplift zones (numbers on map): IV and IV - Privakhsh-Eshkamesh; V - Kafirnigan-Khaybak-Kunduz; VI - Andkhoy-Kugitang-Surkhan Tau; VII - Paropamisus to Koh-i-Elburz; 4 - the Baysun cauldron; 5 - west margin of the upper Amu Dar'ya depression; 6 - boundaries of the uplifted and depressed zones; 7 - axes of the main structures; 8 - salt domes; 9 - frontier; 10 - deposits of oil and gas at present worked (numbers on map): 1 - Khau Dag; 2 - Kokayty; 3 - Lyal'-Mikar; 11 - deposits worked out in the upper units, Lower Cretaceous and older deposits unexplored (number on map): 4 - Uch Kyzyl; 12 - structures under exploration (numbers on map): 5 - Ashirkhan; 6 - Kyzyl Tumshuk; 13 - structures already surveyed (numbers of map): 7 - Staro-Temez; 8 - Ak Kurgan; 9 - Dzhayrankhan; 10 - Boz Rabat-Ak Tash; 11 - Gadzhak; 12 - Shaambar; 13 - Andygen; 14 - Kara Dum; 15 - Kafryuk; 14 - structures detected from geomorphologic signs and confirmed geophysically (numbers on map): 16 - Taskan; 17 - Boldir; 15 - structures detected geophysically (numbers on map): 5 - Ashirkhan; 6 - Ak Kurgan.


Samarkand
Zeravshan
Zakhmatabad
Anzob
Garm
Stalin M.
Peter the First Range
Darvaz Range
Vanch Range
Yazgulum Range
L. Sarez
Rushan Range
Shugnan Range
L. Yashil Kul'
Karl Marx M.
Vakhan Range
Kalai Pyandzh
Khorog
L. Shiva
Kukhb Laa R.
Fayzabad
Dzhirm
Zebak
Kila Drasan
Masuudzh
Chitral
Dila Drosh
Esmar
Kashmund Range
Tigir
Charikar
Kabul
Pagman Range
Khodja Mohammed
Safed-i-Khirs Range
Kugi-Ten R.
Obi Mazar
Kara Tegin Range
Stalinabad
Ordzhenikidzebad
Bakhsh
Ak Su
Kara Tau R.
Obikiik
Kurgan Tyube
Vakhshstroy
Kukhe
Rustak
Meshed
Keshma
Derairn
Kukhe Talikan
Talikan
Kunduz
Khanabad
Eshkamosh
Nakhrein
Shashan Range
Anderab
Doshi
Baglan
Ak Tau Range
Baba Tag R.
Surkhan Dar'ya
Regar
Sary Assiya
Uzun
Denau
Baysun
Baysun Tau R.
Khau Dag
Kugitang Tau
Kelif
Derbent
Gissar Range
Zeravshan Range
Urgut
Pendzhikent
Chanyl Kalyan R.
Kitab
Shakhrisabz
Chirakchi
Yankabag
Karshi
Kamashi
Guzar
Dekhanabad
Guzar Dar'ya
Amu Dar'ya
Mukry
Khanabad
Akhcha
Balkh
Khul'ya
Tashkurgan
Khodzha Gur
Asiabad
Khaybak
Koh-i-Shadian Range
Koh-i-Elburz
Dera Gaz
Kala Sarkali (Dara-i-Sufy)
Shibirgan
Chadar Tepe
Sary Pul'
Mirze Baleng R.
Khargara
Fereud Range
Sardab
Koh-i-Baba Range
Paropamisus
Dasht-i-Kasym
Andkhoy
Abi Koysar
Douletabad
Meymene
Bel'chirgar
Band-i-Turkestan Range
Bala Murghab
Murghab
Kala-i-Nau
Kara Bil' uplands
0 25 50 75 100 km

uplift domes. The zone contains a great variety of types of structure, such as domes, anticlines of cupola shape (cryptovolcanic structures), anticlines, adaptation folds, terraces, faults, and so on. It is common to find in a fold system structures whose direction is normal to that of the system generally, or nearly so. The commonest types of structure here are the cupola-shaped anticlines and the compound anticlines, which are cryptovolcanic; the cryptovolcanic type includes the Angot uplift (in the region of Sar-i-Pul), which lies in this zone.

The Afghanistan Ministry of Planning recently ("World Oil", 147, No. 6, 1958; Survey of Progress) stated that two boreholes were drilled in the Angot structure in the spring of 1958; the second reached oil-bearing strata at a depth of 1120 m. This news deserves the utmost attention, for oil in a cryptovolcanic structure may be of pyrolytic origin (from organic matter present in sediments), as at Furbero (Mexico), Baton (Morocco), Hurgad (Egypt), Akita (Japan), Paromay and Nutovo (Sakhalin), and so on. Conversely, cryptovolcanic structures may indicate the presence of oil. There are many large domes within this zone, and many of these may be the basis of local cryptovolcanic structures.

The adjacent Khaybak-Kunduz zone to the east meets the above zone on the 68° meridian near Tashkurgan; the submeridional structures in this zone continue from the west and have their northern periclines abutting the southern sides of large structures of latitudinal strike (the Koh-i-Shadian and Khodja Gut). There is a tendency for the folds of northwest strike in this zone to intersect or cut short the folds of latitudinal strike in the previous zone, which about 45 km to the east (along the southeast continuation of the Shamar anticlines) is cut short by the Khaybak-Kunduz uplift zone; thereafter we find folds of northwest strike. The structures of the Khaybak-Kunduz zone have very prominent outlines; they are narrow and steep. Popol and Tromp consider that these structures are related to faults in the basement and to differential movements of blocks of various sizes, which would make them adaptation or junction structures. The northern ends of some folds in this zone run nearly normal to the southern flanks of the eastern parts of the Koh-i-Shaidan and Khodzha Gut ranges; one of the above structures meets the Khodzha Gut Range at right angles. The axis of the submeridional fold intersecting this range may be followed for several kilometers north of the range towards the Amu Dar'ya. The Shamar fold, which belongs to the Khaybak-Kunduz system, extends almost up to the southern pericline part of the Koyki Tau structure, which lies on the right bank of the Amu Dar'ya in the Kafirnigan uplift zone. Here we have a point of junction between the southern and northern margins of the upper Amu Dar'ya depression.

This junction of the Kafirnigan and Khaybak-Kunduz zones reveals some very interesting effects. The first zone starts almost at right angles to the Gissar Range and is somewhat curved; the normal to the chord of the curve points northwest. There is a similar relation between the second zone and the Hindu Kush; the former starts out from the Hindu Kush almost at a right angle, the corresponding direction being west-northwest. These two zones together form an arc facing westward, which joins the two margins of the depression. The sections and occurrence of the various stratigraphic units in the Soviet part would indicate that the zone has some important paleographic features; the structure of the southern pericline part of the Koyki Tau indicates that rocks younger than Paleogene play no part in this junction, which means that here we have a relatively higher uplift. This may have acted as a barrier in the Late Tertiary (and in the Late Quaternary) between the Kurgan Tyube-Khanabad and Surkhan-Balkh depressed zones. The uplift is clear from the morphology; outliers of the Koyki Tau (heights up to 1300 m) stretch down to the river from the north side, while on the south side there is the Shamar anticline (height about 600 m). The upper terrace of the Amu Dar'ya lies at 400 m, though it falls to 300 m about 50 km downstream.

The most recent movements are confirmed by the thick strata in the isolated depressions, as well as by the dislocation of the Quaternary strata, which occur (Burachek and Borneman) in the Kulyaba-Rustak depressed zones and as the 400 m Quarternary beds revealed by borings in the Ashirkhan structure and in the Surkhan-Balkh zone, which lies between the Shirabad-Sarykamysh Ridge and Khau Dag.

3. CONCLUSIONS

The map for the structural morphology of the depression shows that the raised and depressed zones have almost equal areas. The zones differ greatly in strike, and in places the lines are almost perpendicular. This shows that we have a massif split up into large blocks by broad belts of deep faults in the uplift zones, not linear folding of geosynclinal type.

These blocks, or rather the boundaries between zones, are often very prominent; this is so when the boundaries coincide with major elements such as the Baba Tag and Tuyun Tau ranges (west margin of the Surkhan-Balkh zone), along the Koh-i-Elburx, Koh-i-Shadian, and Khodja Gut (south margin), and the Kelif-Sarykamysh Ridge (west margin). Considerably less folding occurs towards the interior of that zone, in which we find mainly dome-shaped

folds, which are commonly of cryptovolcanic type.

The uplift zone in the Paropamisus to Khoi-Elbruz region reveals that the largest uplift zones preserve the regional structures of the depression as a whole. The minor structures in this zone have various orientations, and they include all genetic types from domes to junctions.

The new information confirms my earlier deduction that the depression is the southeastern continuation of the Kara-Kum platform and has undergone substantial deformation and reconstruction.

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All-Union Oil Exploration
Research Institute
Ministry of Geology and Conservation
Leningrad

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STRATIGRAPHY AND CRYOGENY OF THE QUATERNARY IN THE VALLEY OF THE YANA[1]

by

N. P. Kuprina, and B. I. Btyurin

The Quaternary beds in this valley were detected in the last century; the early studies in the area by Toll' [16], Bunge [1], and Vollosovich [3] indicated that the formations following the Tertiary have an unusual structure in northeastern Yakutia. The major bodies of underground ice are of particular interest. The vein theory cannot explain the great thickness of these bodies, which are assumed to be the remains of buried glaciers [3, 8, 16]. Only during the last decade it was demonstrated [12, 19] that the major bodies are syngenetic with the surrounding beds; nevertheless, the fact has not yet been generally accepted by geologists, and so in 1958 we made a field study in the valley of the Yana, from Batygay to the delta.

The upper part of the valley (from the junction of the Sartang and Dulgalakh to Batygay) lies in the Verkhoyansk depression, which contains thick porous sandy strata. Most of the valley lies in the Yana uplands, which consist of Triassic and Jurassic sand and clay; the plateau lies at a height of 400 to 500 m. This part of the valley consists of a sequence of narrow straight sections and wide parts with islands and meanders; the width of the valley ranges from 1. 2 to 20 km, and that of the bed from 0. 7 to 1. 2 km. The plateau is separated from the Primorya lowlands to the north by the Kular Ridge, which is very prominent in the relief.

The Primorya lowlands form an extensive and very marshy plain consisting of thick sediments; the maximum height in the plain is 50 to 70 m (at the foot of the Kular Rigde), and the plain is inclined gently towards the sea. Thermokarst relief forms are common; lakes are numerous. The valley changes in type when it enters the lowlands; the bed becomes much wider (1. 8 km at Kazach'ye), and there are many islands and channels.

Four terraces can be distinguished; the oldest Quaternary deposits lie in terrace IV, which is 30 m high (Figure 1). This terrace stands out in the relief; it can be traced in the depression, and even in places in the uplands, as a sharp drop and a level surface. The terrace is generally accumulative and is composed of dark-gray or dark-brown fine-grained sands with slight oblique bedding; there are narrow bands of medium-grained sand. The basin of the Yana lies in the permafrost zone, so the unconsolidated sediments have some features not present in such deposits before freezing. Ice bodies of various shapes and dispositions occur, the precise situation being governed by the type of rock and conditions of freezing. The sands of terrace IV have a massive cryogenic texture (i. e., they are sandstones cemented by ice alone). The surfaces of the terrace have micro-relief produced by polygonal cracking; there are epigenetic (Recent) veins of ice from a depth of 0. 45 m.

The heavy fraction of the terrace IV sands contains much amphibole (30 to 40%) with epidote, tourmaline, mica, apatite, zircon, and silimanite; there are many weathered unidentifiable grains, but there is hardly any garnet, which V. I. Muravyev (who performed the analyses) takes to indicate acid humid weathering (garnet is then rapidly destroyed). Up to 50% of the light fraction consists of quartz, and here there are many opaque weathered grains; there are comparatively fresh potash feldspars, and many grains are coated with iron.

Analyses have been made in many specimens from the alluvial deposits of terrace IV, but only one yielded spores and pollen sufficient for counting. The pollen is dominated by types from grasses and shrubs (67%); tree types are represented by rare grains from Alnus (probably creeping) and Betula (woodland and creeping forms). No animal remains were found, so the age of the deposits is very difficult to determine. Comparison of terrace IV with terrace III (which is dated as the end of the Middle Pleistocene or the start of the Late Pleistocene; see below) indicates that terrace IV was complete by the end of the Middle Pleistocene. The

[1]Stratigrafiya i kriogennye osobennosti Chetvertichnykh otlozheniy v doline Yany, (pp.76-87).

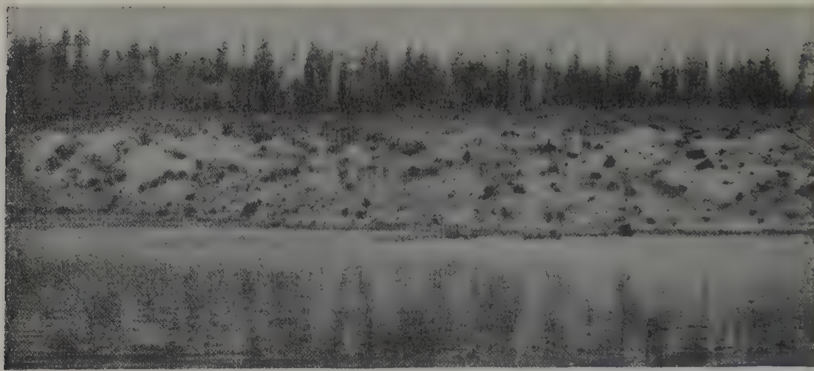

FIGURE 1. Terrace IV 2 km above the Tarbachanakh.

terrace was formed under unusual conditions, for the alluvium is very thick and is of unusual sandy composition; the valley received enormous amounts of water, perhaps on account of climatic changes (e. g., melting of glaciers). Coarse material is absent, so the glaciers must have been fairly distant. This conception is in accord with the acid humid weathering, which points to a cold and humid climate with a wooded tundra. The lack of vein ice and the massive cryogenic structure indicate that conditions were not favorable to freezing to great depths in the winter while the deposits were being laid down. All we can say is that terrace IV subsequently underwent epigenetic freezing.

Terrace III gives the best evidence on the age; it occurs extensively in the hilly parts of the valley, where it is 25 to 27 m high (areas of 30 to 35 m occur in places, on account of local uplift). The eluvial deposits remain of much the same thickness and type at all points; the tectonic movements occurred after the terrace was formed. These deposits contain much ice; vein ice is exposed in landslips and is revealed also by specific relief forms on the surface, which have been produced by melting of the vein ice.

The surface is made up of deluvial and solifluction deposits, which are yellow to brown unbedded sandy mudstones 0. 8 to 1. 2 m thick; under this there is a layer of peat about 3 m thick, which contains hardly any mineral inclusions. Next there is a bed of dark gray clayey sand of very small grain size, which has oblique or horizontal bedding and is up to 15 m thick. At the bottom there is coarser material, which grades into a sand containing bands of pebbles and then into a pebble bed.

This structure occurs in all sections of terrace III; variations in thickness occur only in the peat and pebble beds, peat being almost absent in certain cases. The visible thickness of the pebble bed is dependent on the position of the foot; the greatest is 12 m. The bed is in places almost entirely below the water line, in which case only isolated stones squeezed out along contacts with ice veins are to be seen.

The terrace is penetrated by thick veins of ice; the layer of seasonal thawing is here only 0. 6 m deep at most, and the tops of the veins lie at depths of 0. 8 m or more, so the veins are to be reckoned as buried. The veins are up to 3 m wide at the top, the vertical lengths being 25 to 30 m. Such lengths imply syngenesis, which is evident also from the banding in veins whose tops emerge at lateral contacts. These veins start at different depths, with 0. 8 m usual for the top and 20 m for the base. There are differences of texture between veins whose growth stopped at 20 m and those whose growth extends to the current level of the terrace; the first have very regular and prominent vertical banding, with large amounts of solid inclusions and a few gas bubbles, the color being dark gray. The second have no such regular banding, especially in their upper parts; gas bubbles are dominant, and the color is light gray. The lower parts resemble those of veins whose growth stopped at 20 m. The initial conditions were clearly the same for both types but some veins later ceased to grow upwards, while those that did encountered rather different conditions.

The cryogenic texture is massive with microbanding (rarely cellular) in the lower part of the section; the cellular feature is most common in clayey material containing much mud. In places, the streaks of segregation ice in that texture are so thin that the texture appears at first sight massive; careful examination is required in order to distinguish the network. A curious porphyritic texture is found in peaty areas; the segregation ice occurs as nodules of various sizes.

Another interesting feature of terrace III is

is a surface layer of broken rock deluvium 10 to 15 m thick; the thickness decreases downstream, and the level of the terrace falls. This deluvium contains fairly thick ice veins although it is coarse, because it is unusually rich in ice. Here we have an ice cement of basal type; the broken rock is in suspension in ice almost free from inclusions, apart from small spherical gas bubbles in places where the ice is thick. The cryogenic texture of the deluvium may be termed basal, by reference to the ice cement.

Ice veins are present in the deluvial and alluvial deposits, apart from river-bed pebble bands. Two stages are generally visible in the system of ice veins. The lower stage consists of syngenetic veins 10 m or more in vertical length and 2 to 3 m wide at the top, while the upper one consists mainly of epigenetic veins that grew in the deluvium and that have penetrated into the underlying alluvial beds and even into the veins of the lower stage; this upper stage consists of veins 5 to 7 m long and on the average 2 m wide at the top (widths of over 3 m occur). A stage consisting of epigenetic veins is in places visible within the upper stage; these consist of small intergrowths whose tops extend up to the level of maximum current thawing. They are clearly Recent, and are seldom more than 1 m wide at the top or 3 to 4 m long. If these are reckoned as a separate stage, there are two epigenetic stages in the deluvium and a syngenetic stage in the alluvium. The stages differ greatly in structure; the syngenetic veins have prominent vertical banding, numerous solid inclusions, and relatively few gas bubbles. The ice is dark gray. The large epigenetic veins have weak vertical banding, many gas bubbles, and few solid inclusions (apart from numerous pieces of broken rock); the ice is light gray. The lateral contacts of the veins in the broken rock are not clear; there is a gradual transition to ice cement. The small epigenetic veins have milk-white ice with very slight and uneven vertical banding; the inclusions are very numerous and consist mainly of small bubbles with some small rock fragments. The veins of the lower and middle stages are buried.

There is also ice in the erosion (thermokarst) cavities, which is of infiltration or runoff origin; it always accompanied vein ice. These thermokarst columns are visible in every exposure of thick fossil ice.

Sometimes the section shows veins of the lower stage, streaks of segregation ice in the rock, ice in the thermokarst cavities, epigenetic segregation streaks in the saturated soil around the cavities, and veins of the middle stage; all of these may be variously arranged in space.

The spore and pollen spectra (see [5] for the diagram) for terrace III are dominated by pollen from grassland plants (85 to 97%); there is only 1 to 7% tree pollen, which includes that from Betula (creeping form), Betula sp., and Alnus. The grassland plants are Gramineae, Cyperaceae, Artemisia, Compositae, Caryophyllaceae, and so on. The spectra are of tundra type, for cryophilic species such as Cerastium sibirica and C. maximum are present.

About 50 bones of mammals were recovered from this terrace, mainly from the floodplain alluvium; these were of Mammuthus (Elephas) primigenius (early type), Rhinoceros antiquitatis Blum., Bison priscus Boj., Rangifer tarandus L., Equus caballus L. (large and small forms), Canis lupus L., Lepus sp., and so on. We are indebted to E. A. Vangeygeym (Geological Institute, Academy of Sciences) for identifying these.

We discovered several deposits of animal remains from which Bunge made substantial collections. For example, we found a tooth of M. Primigenius (early type) and a fragment of the skull of Bison priscus deminutus W.-Grom. (short-horned form), in an exposure 0.5 km above the mouth of the Ulakhan Oldye (Bunge [18] calls this an exposure on the Insyugen); this river enters the Yana about 3.5 km below the Batan Tay. Here Bunge found skull fragments of Bos. some remains of Elephas (mammoths), and a poorly preserved skull of Rhinoceros; he remarks that there were no remains of Ovibos. We examined all the localities and made additional collections of fossils, which enabled us to deduce the age of the alluvium. All finds belong to the Upper Paleolithic complex, which Gromov assigns to the second half of the maximal (Riess) glaciation before the Holocene. The early mammoth remains give the age as end of the Middle Pleistocene to start of the Late Pleistocene [7].

There are extensive deposits in the Primorya lowlands comparable to terrace III; these are 30 to 40 m thick, and they are well exposed at Mus Khay (on the left bank of the Yana, 50 km above Kazach'ye (Figure 2). (We shall not describe this in detail, for Katasonov [10] gives much space to it.) The exposure is 30 to 35 m high; at the top there are deluvial solifluction deposits 1.5 to 2 m thick, which are clays with varying amounts of fine sand. Below this there is a 30 m layer of similar material containing lenses and bands of peat; Katasonov distinguished seven floodplain beds in this. Each starts with clayey sand, grades into nearly pure clay, and ends in a peat lens; the lower bands in each bed are deflected upwards at the contacts with ice veins and are covered in the center by almost horizontal bands.

Veins of fossil ice occur in these deposits; they are over 30 m long and 6 to 8 m wide at the top. These are syngenetic; the vertical banding is even and sharp at the bottom, but rather

FIGURE 2. Detail of the Mus-Khay exposure.

uneven and blurred at the top. The proportion of solid inclusions decreases upwards, but the proportion of gas bubbles increases. Some of the veins ceased to grow while the deposits were being formed; the tops of the veins now lie at depths between 0.8 and 20 m. There is no tendency for the tops to lie at any special levels; the 0.8 m depth is associated with the conversion of the floodplain to a terrace (with the reduced water content resulting from better drainage).

Lower down there are fine-grained sands of dark gray color, visible thickness 3 m. Borings made by the Permafrost Institute of the Academy indicate that these sands extend an additional 2 m below the level of the river and lie on rock.

At first sight, the section as a whole appears not to differ from a normal alluvial section, for all the main groups of alluvial facies are present. But the entire set of deposits could not have formed in the usual way without floods 30 to 35 m deep, which are very unlikely. It is much more likely that the lowlands were gradually sinking, in which case the 30 m series is not merely a floodplain facies; here we have the special subarctic type of plain alluvium, whose mechanism of formation is not clear at the present time.

We collected some 70 fragments of mammal bones from the Mus Khay exposure; many others have been collected by workers from the Permafrost Institute (Institut Merzlotovedeniya), who are examining the area in 1961-2. The typical fossils of the Upper Paleolithic complex here include teeth of M. primigenius (early type), which means that the deposits were formed at the end of the Middle Pleistocene. This age would not conflict with Shumskiy's finds of Bison priscus longicornis W. Grom. in these deposits, for there is as yet no convincing evidence that this form is indicative of times preceding the maximum glaciation of Siberia; the long-horned and short-horned forms of Bison have been found together in other parts of Siberia [14].

The spore and pollen spectrum is of tundra type, for the pollen is dominated by grassland plants, especially numerous cryophilic species.

These deposits may reasonably be correlated with terrace III on the basis of the fossils, pollen, and cryogenic structure; the two are of the same age (end of Middle Pleistocene or start of Late Pleistocene). Various ages have been assigned to them in the past, as the following review shows.

Strelkov (p. 153 of [15]) assigns "the main part of the visible deposits of the Primorya lowlands to the second Late Quaternary interglacial" because "the plain grades into a continuous alluvial terrace 30 to 40 m high as we pass up the rivers, and this is much younger than the Zyryan glaciation".

This conclusion is in conflict with the following evidence. The spore-pollen analyses and cryogenic structure of the lowlands suggest a very harsh climate, so it would be more correct to assign the deposits to a glacial period,

especially since the younger deposits relate to conditions of a wooded tundra. The finds of early mammoths imply that the deposits cannot be more recent than the end of the Late Pleistocene.

Katasonov agrees with us in assigning the lowland deposits to the boundary between the Middle and Upper divisions of the Pleistocene, but he considers that they may be correlated with the very unusual sand and pebble beds of the Omoloy, although thermophilic flora were known in that area even in Vollosovich's day. He bases his correlation on Khmyznikov's [17] evidence that the deposits belong to a single terrace standing above a floodplain; he considers that "it has not yet been demonstrated that the Omoloy sand and pebble formations belong to any other geomorphologic element, nor has an earlier date been proved for Picea Volossovichii, so we would do best to consider these unusual formations as a special facies (such as Shantser's pool and ridge facies) of an alluvial complex characterized by mammoth fossils".

We cannot accept this conclusion, for the assignment to a single terrace is based solely on heights, which cannot serve as a serious proof of identity in age. Moreover, recent geologic surveys by the Institute of Arctic Geology in the area indicate that these sand and pebble beds containing Picea Volossovichii appear on the surface at heights above sea level ranging from 10 to 80 m, which would not justify an assignment to a single terrace level. The lowland beds have a spore-pollen spectrum of tundra type, whereas some [11] would assign the Omoloy flora to the Arctic Tertiary; i. e., before the Pliocene. It would seem quite unjustified to assign beds with such distinctive flora merely to distinct facies of a single alluvial complex.

Terrace II is easily seen in the valley of the Yana; it ranges in height above the floodplain from 15 to 20 m, and it can be traced in the uplands as well as in the lowlands. A point here is that the base is usually visible in the uplands, whereas even the river-bed facies stands no more than 1 or 1. 5 m above the water line in the lowlands. Terrace II resembles terrace III in type and structure; it is clearly seen as a step having a very uneven surface (again, on account of thawing of ice veins). The remains of polygons (baydzharakh) are usually easily seen near the river (Figure 3).

The terrace in the uplands is composed of dark bluish silty clay 5 to 7 m thick, which at the base grades into sand and then into pebble beds which are 4 to 5 m thick, and the pebbles are poorly graded and only slightly worn. The base usually stands at a height of 6 m, except around Yana Gorge and within Kular Ridge, where its height is 10 m. The top of the terrace carries deluvial and solifluction clays 0. 4 to 0. 8 m thick.

The terrace has a rather different structure in the lowlands, where it extends almost down to the delta. Here we may distinguish two typical sections, of which the first is similar to that of the uplands apart from a greater thickness in the floodplain alluvium, which consists of clay with many plant fossils. Here the riverbed unit, which consists of pebbles, stands no more than 1. 5 m above the water line. The transition from this type to the other type of section can be seen along the Dering Ayyan; the main difference is that the fine-grained clays (with some sand) give way to poorly graded sand of medium grain size. The same change of facies can be seen along the Samandon. The height of the terrace is reduced by 2 to 3 m, on account of the change in ice content; the clays contain prominent syngenetic ice veins whose vertical lengths are up to 15 m. The veins are not usually wider than 3 m at the top; they differ from those of terrace III in that the ice shows less vertical variation in structure, is gray, and has clear vertical banding. Plant remains occur in the ice.

FIGURE 3. Baydzharakh in terrace III 0.5 km above the Ulakhan-Oldye.

The proportion of ice in the sands is much smaller; the sands usually have a massive cryogenic structure. The growth forms indicate that the veins are syngenetic, but they are smaller (lengths up to 10 m, width at the top 1 to 1.5 m) and form widely spaced networks. The vertical banding is always clear and even, on account of the abundant solid inclusions.

Mammal bones have been collected from terrace II, but much fewer than for terrace III; they belong exclusively to the Madla fauna of the Upper Paleolithic complex [7]. The spore-pollen spectrum contains from 15 to 45% of trees such as Larix, Pinus pumila, Alnus, and Betula (woodland and dwarf forms). There is from 53 to 76% of pollen from other plants, which are mainly Gramineae, Compositae, Artemisia, and various grassland plants. The spores make up from 1 to 10% of the total and include material from Filicales, Selaginella sibirica, Sphagnales, and so on. The spectrum is of wooded-tundra type. The evidence indicates that the deposits of terrace II were formed in the Upper Pleistocene.

Only fragments of the lowest terrace (height 12 to 13 m) are present; it differs sharply in structure from the floodplain and from the other terraces. The deposits are mainly sand and loam, with many thin bands of allochthonous peat. Pebble beds and gravel play some part in places, as at the mouth of the Aducha and in Kular Ridge. A typical section occurs on the left bank at the confluence with the Oulbut (about 50 km below Batygay); at the top there is the soil (0.3 m), which is followed by a gray fine-grained sand in places containing much iron or silt (0.3 to 1.0 m). The thin horizontal beds stand out on account of bands of extraneous organic material. The permafrost zone begins at a depth of 0.4 to 0.5 m; here the sand has a massive cryogenic structure, and only in some places do we find a varved clay containing much silt. A buried peat-soil horizon lies at 1 to 1.2 m; at the top of this there are the roots and branches of shrubs and the stumps of trees. Somewhat decayed roots of herbaceous plants penetrate 0.2 m below this layer. Then follows a fairly homogeneous body of sand and loam, which has thin bands of organic material; this extends down to the water line. This part shows flow bedding in the sand, with a microcellular or massive structure in the loam. The proportion of ice becomes high only near contacts with ice veins.

The loss of vein ice near exposures reveals a network of large polygons, which had veins 0.5 to 0.8 m wide at 5 to 6 m below the surface. The contacts at this level are epigenetic; the veins taper off rapidly lower down. We did not observe marshy centers to the polygons in this terrace. The vertical banding in the ice is prominent; the bands are 3 to 5 mm wide, and the layers carrying the foreign particles (sand) are 0.5 mm wide. The ice itself is of small grain size.

The ice veins generally are epigenetic in this terrace, which has yielded no animal fossils apart from a few unidentifiable water-worn bones.

A sequence of gravel and gray or yellow-green fine sand is present in this terrace on the left bank of the Yana 2 km below the mouth of the Adycha; the bands range in thickness from 0.45 to 2.5 m, and the deposits contain abundant plant remains. The spore-pollen spectrum is distinctive in that it is very much dominated by tree pollen (up to 82%), the pollen being from Alnus (53 to 80%), Pinus sp., Pinus subfamily Cembrae, Pinus pumila (10-20%). Larix (5-23%), Betula (woodland and creeping forms), with rare grains from Picea and Salix. The herbaceous pollen accounts for only 20%. Yu. M. Trofimov has identified the following: Picea sp., Pinus sp., Alnus fruticosa, Arctosaphylos alpina Spr., Rubus ideaus L., Cicuta virosa L., Carex rostrata Stok., and Artemisia borealis Pall. The spectra at present known for terrace I of the Indirgirka contain no pollen from woodland trees (personal communication from R. Ye. Giterman), so the material must be interpreted very carefully. It is quite possible that here we have the remains of older deposits.

We assign the deposits of terrace I to the second half of the Upper Pleistocene on the basis of comparisons with terrace II and with the floodplain.

The floodplain is of irregular occurrence in the valley of the Yana; its area is very small in the hilly parts and falls to zero in Kular Ridge, but it expands rapidly when the plain is entered. The floodplain encompasses practically all of the delta. There are three levels, which differ also in type of deposit and in cryogenic structure. The high floodplain reaches up to 8 m in the hills, up to 6 m in the plain, and up to 2 m in the delta; its surface usually shows prominent polygonal-fissure microrelief from heaving (growing polygons) and thermokarst effects (shrinking polygons). This relief in all stages of development is best seen in the lowlands. The floodplain is made up of sand (medium and fine); the bed is 4 to 6 m thick in the hills. The river-bed deposits are mainly pebbles. Ice veins occur in the deposits in the hills only in very peaty areas; they are then clearly syngenetic (Figure 4).

The middle level stands 3 to 4 m above the flood level of the river in the hills; the deposits consist of fine sand and loam with many bands of plant remains. There is no microrelief as in the previous level nor any ice veins in the hills; but the veins and that relief both start in this level in the lowlands. The low level occurs only in small areas where the banks have been

FIGURE 4. Type of deposits in the high floodplain in the middle reaches of the Yana.

under attack; it grades into the middle level, although in places there is a small step. Its structure is as for the middle level.

The deposits of all three levels are very thick and peaty in the lowlands; they are also of small particle size.

Only part (the upper half) of the Quaternary system is represented in this area of Yakutia; the section gives clear evidence of climatic variations during this period, and so we again confirm [2] that Cherskiy [18] and Popov [13] were wrong to conclude that the climate of northeast Asia was moist and mild throughout the Pleistocene.

The area is a periglacial zone, for glacial deposits are lacking. The permafrost set in during the formation of terrace III on the Yana (at the end of the Middle Pleistocene), for signs of syngenetic ice are absent from the earlier deposits. The problem demands a detailed study of the Lower Quarternary deposits in adjacent areas along the Omoloy and in the basin of the Indigirka.

CONCLUSIONS

Geocryology must be considered in relation to the stratigraphy and history of the Quaternary in northeastern Yakutia, although this in isolation can give wrong results. For example, all the Quaternary deposits along the Yana contain ice veins, which might seem to point to a lack of climatic change between the second half of the Middle Pleistocene and the Holocene; but other data point to repeated variations in this period, which would give rise to an apparent conflict. A special study reveals that the ice veins differ as between one terrace and another; the largest syngenetic veins occur in terrace III, which spore-pollen analysis indicates as corresponding to a harsh climate. The veins in terrace II are rather different; those in terrace I are mainly epigenetic.

If we associate the veins with glacial epochs [9], we would extend these from the second half of the Middle Pleistocene to the Holocene, which is not the case.

Our results show that the stratigraphy of the Quaternary in the valley of the Yana and in the Primorya lowlands demands the use of biostratigraphic, lithologic, geocryogenic, and geomorphologic approaches.

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Geological Institute, Academy of Sciences, U. S. S. R., and
Permafrost Institute, Academy of Sciences, U. S. S. R., Moscow

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BRIEF COMMUNICATIONS

NEW LIGHT ON RECENT TECTONIC MOVEMENTS IN WESTERN AZERBAIJAN AND EASTERN GEORGIA[1]

by

M. G. Agabekov, and A. V. Mamedov

Studies of recent tectonic movements show that the structures produced by the most recent crustal movements must be given serious attention in understanding the tectonics of any given region. These movements reflect tectonic processes that occurred in the Neogene (in part) and in the Anthropogene; they are responsible for the main features of the present relief. Many major engineering projects could not be undertaken without a study of these movements (e. g., hydroelectric stations, reservoirs, canals, and various industrial projects).

Many of the structures in oil fields are the result of neotectonic movements; e. g., buried folds, which occur at the margins of major mountain ranges and at the edges and middle regions of depressions.

We report here a detailed study on the folding at Akhtakhtatap, which lies at the boundary between Azerbaijan and Georgia (Figure 1). The highest point in this range of hills is 760 m, 280 m above the Eriktar valley to the south. The range has an area of 25 km^2. These uplands were formed by neotectonic movements; 18 boreholes have been drilled along five almost parallel lines across the strike of this range, each hole being about 450 to 500 m deep and all being in the Middle Sarmatian beds. Of these, 13 penetrated continental Upper Pliocene deposits (Apsheron beds) via a tectonic contact, whose surface (Figure 2) is almost identical to that of the bedding in the Sarmatian.

The stratigraphy of the beds indicates that the Sarmatian rocks (which have almost horizontal bedding) do not lie in their original site but form an overthrust on the continental beds. Profiles I-I, II-II, and III-III show the largest overthrust; profile II-II shows the contact best, for four boreholes penetrate it. Here the overthrust is 5 km.

The Sarmatian beds began to be thrust upon the Apsheron beds after Apsheron times (in the Quaternary); since then they have advanced 2. 5 km.

The Quaternary has a duration of 1 million years in the scheme of Barell, Schuchert, and Holmes, in which case the speed could have been 2. 5 mm/year. This is commonly accepted as the speed of the most recent tectonic movements. A survey of the geodetic results of 1910, 1926, and 1937 for the Kura lowlands [1, 2] has shown that the surface rose by 30 mm in 11 years in the region of Alyata [1], which implies a speed of 2. 7 mm per/year. This precise figure (from instrumental readings) falls very close to the 2. 5 mm per/year from the borehole estimates, although no allowance has been made in these estimates for subsequent erosion, which might increase the result by a factor of 1. 5 or 2.

This overthrust occurred along the line of the Eriktar overthrust (T in Figure 2); the latter is very extensive and can be followed well to the east and west of the Akhtakhtatap Ridge. The southern edge of the movement lies along this line T, while the northern one lies along the Eldaroyuga overthrust T_1. The mass of Middle Sarmatian rocks occurs between the Eriktar and Eldaroyuga tectonic faults, on both sides of which we have relatively motionless zones (Upper Sarmatian to the north, Lower Sarmatian to the south). These rocks have been thrust to the SW over the Apsheron beds, which has given rise to the Akhtakhtatap Ridge; if this ridge did not extend on the southeastern side into the valley of the Eriktar, and this valley were replaced by a ridge that would hinder the movement of these rocks, the Middle Sarmatian beds would have given rise to a complex folded structure. However, no major obstacle was

[1]Novye dannye o sovremennykh tektonicheskikh dvizheniyakh zapadnovo Azerbaydzhana i vostochnoy Gruzii, (pp.88-92).

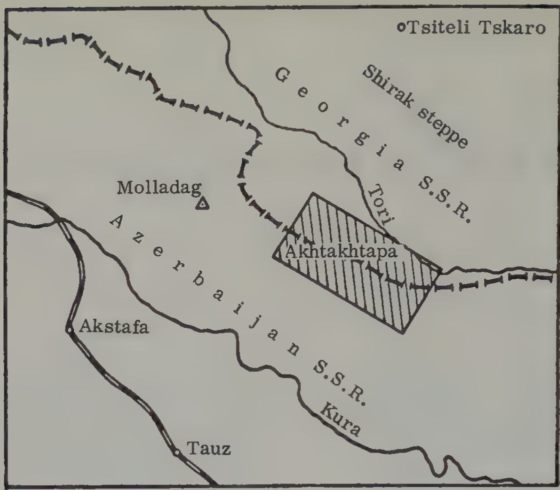

FIGURE 1. General map of the Akhtakhtatapa Ridge and adjacent regions

encountered, so the ridge moved almost horizontally. The problem then arises as to why no ridge resembling this one has appeared along the entire length of these tectonic faults; perhaps the overthrust occurred only within the Akhtakhtatap Range, the rest of the block remaining motionless. But this is not so, for our studies have shown that these faults can be traced for many kilometers beyond this ridge and that the entire mass between these faults has been motionless everywhere. The Middle Sarmatian beds between these faults but outside the ridge consist of sands and clays, so they would soon have been destroyed during an overthrust.

The Middle Sarmatian beds within the ridge have a very different structure; here there are many bands of marl and sandstone, which range up to 5 or 6 m in thickness. These bands act as stiffeners and protect the beds to a certain extent; the gradual movement of the beds has given rise to the ridge.

The VI-VI profile cuts across the eastern end of the ridge; it also meets T and T_1, and it has been based solely on instrument readings for exposures. This profile lies at the very foot of the ridge in the plain. This profile is, orographically speaking, the lowest, being 650 m below the I-I profile. Here T and T_1 are very close together; at other points the overthrust (of Upper Sarmatian beds) causes the lines to diverge, the divergence being maximal around the profiles I-I, II-II, and III-III. This is the middle of the ridge, where its width is greatest. The ridge grades into the plain to the northwest, and here the fault lines come together again.

If we imagine the ridge removed down to the level of the VI-VI profile, we would find that the distance between T and T_1 would remain constant under the existing tectonic cover, as in the plains. This situation is indicated by the broken lines t and t_1, which represent projections of the concealed tectonic contacts.

This ridge reveals the extent of the neotectonic movements in the region between the Kura and Iora, but it is by no means the only feature in this area that points to such movements. Every structural uplift (and there are dozens of them in this region and in the adjacent region of S. Kakhetia to the north) is a clear demonstration of the neotectonic movements in the region.

Khain [3] reports an interesting observation. On the right bank of the Kura 4 km southwest of the Akhtakhtatap Ridge there are Apsheron-Akchagyl beds overthrust onto river terraces near the site of the Akstafa hydroelectric station presently under construction. Borings made in connection with the planning for that station have revealed faults running along the valley of the Kura, and these are coupled to the river terraces. This feature must be considered carefully by those responsible for the station, for it might in the future give rise to a major hazard for this large project. This example is also evidence for neotectonic movements occurring after the formation of the Akhtakhtatap overthrust;

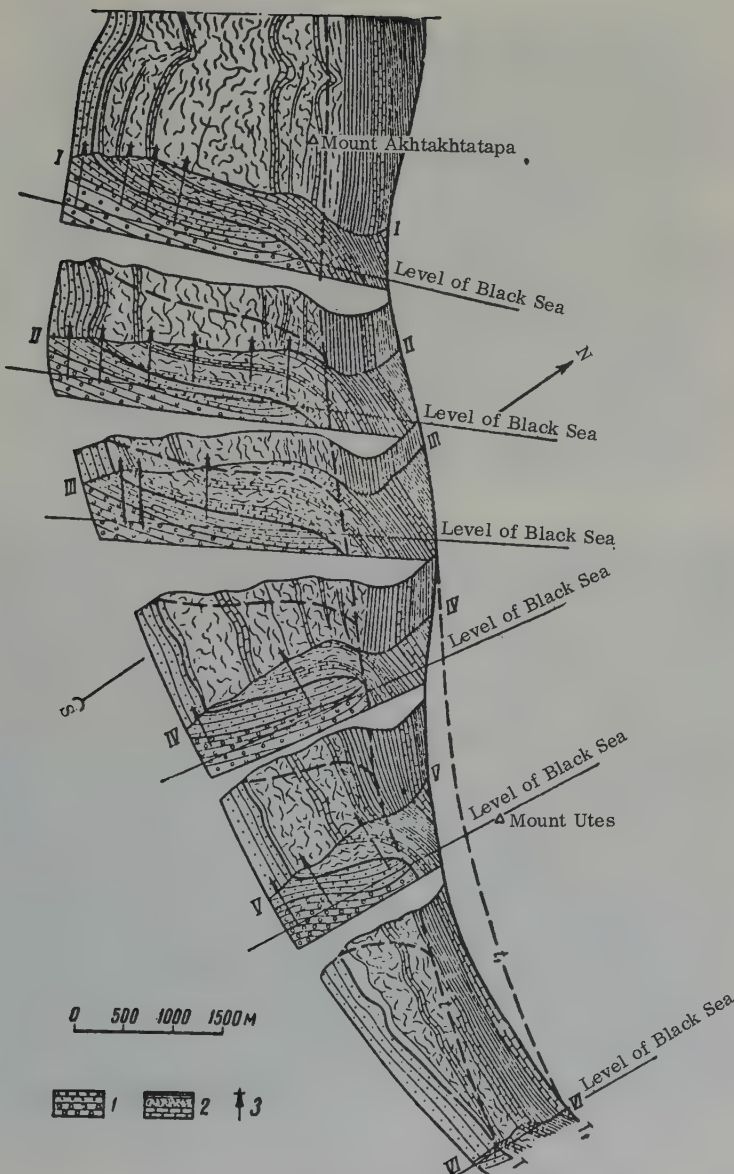

FIGURE 2. Block diagram of the structure of the Akhtakhtatapa Ridge from instrument survey and from structure boreholes

1 - continental beds, Apsheron stage; 2 - Sarmatian beds; 3 - boreholes; T - Eriktar overthrust; T_1 - Eldaroyuga overthrust; t - projection of the Eriktar overthrust on the overburden; t_1 - projection of the Eldaroyuga overthrust on the overburden.

i. e, ones that occurred very recently or are still active.

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Institute of Geology,
Academy of Sciences of the Azerb.
S. S. R., Baku

Receiver, 2 November 1959

BRACHIOPODS AND CRINOIDS IN TALC-CHLORITE ROCKS IN THE SOUTHERN URAL[2]

by

K. I. Postoyev, and G. N. Bezrukov

Considerable interest is centered around fossils in altered rocks, especially highly metamorphic ones, for they give an indication of the nature and genesis of the original rocks. This makes a survey[3] of such fossils as found here and abroad of special interest; it is pointed out repeatedly that the imprint of the fossil often retains all fine details in spite of the changes that have occurred.

We encountered such fossils in 1958-59 in the then newly exploited deposits of talc-chlorite rocks at Bol'shaya Polyana, which lie 4 to 4.5 km south of Ural-Dach in Mias district, Chelyabinsk region. The district is made up of various rock complexes, which are mainly submeridional in strike. The commonest are schists, mainly quartz-mica and quartz-chlorite-mica types; there are also many limestones, dolomites, and marbles. The intrusive rocks are mainly granite, vein series being common.

The Talc-chlorite rocks of Bol'shaya Polyana trend southeast; at their southwestern margin there are bedded siliceous chlorite shale and lenses of carbonate, the latter up to 500 m long. On the north there is a narrow belt of granite with some bands of limestone and dolomite; the dolomite extends to the southeast as a very narrow belt along the left bank of the Atlyan. The belt of carbonates is directly adjacent to the talc-chlorite formations, which grade into chloritites (siliceous or otherwise) at the southern end of the deposits. Thick floodplain deposits of the Atlyan separate the deposits to the north and northeast from the large Atlyan intrusion, vein from which penetrate the deposits.

On the whole, the deposits have a fairly complicated structure on account of the inclusion of lenses of dolomite, chlorite shale, and siliceous-chlorite shale. A schematic section (from the top downwards) is as follows.

The beds of talc-chlorite shale grade into bedded siliceous chloritite, which is followed by a narrow band of chlorite shale which lie on very much weathered rocks, originally of quartz-chlorite composition. More talc-chlorite shale (with much tremolite) appears at a depth of 88 m; these beds have many fossil imprints, which are dated as D_3-C_1. These fossils have been entirely replaced by talc-tremolite-chlorite. M. A. Rzhonsnitskaya (senior scientific assistant, V. S. G. E. I.) has identified the following forms, which are, unfortunately, in a poor state of preservation: Leptaena (?) (Figures 1-3): Schellivienella sp. indet., Lingula sp. indet., Camarotoechia sp. indet., and Strophomenida (?).

Underlying these beds are dolomites, which retain the imprints of a microfauna, to which E. A. Reytlinger assigns a preliminary age of C_1. The entire complex dips 45 to 60° to the west.

The fossils are well preserved (stuations on the shells and crinoids are visible), indicating that the alteration proceeded without substantial change in volume.

The talc-chlorite rocks have the following composition (analyst M. Boyarshinova):

1. SiO_2—49.3
2. MgO—26.59
3. Al_2O_3—7.19
4. Fe_2O_3—7.99
5. CaO—2.45
6. Loss on firing 6.55
7. Insoluble in HCl—79.29

[2] Obnaruzheniye ostatkov fauny brakhiopod i krinoiday v tal'ko-khloritovykh porodakh na yuzhnom Urale, (pp. 92-95).

[3] E.V. Pavlovskiy and N.F. Frolova, Organicheskiye ostatki v metamorficheskikh kompleksakh. Izv. Akad. Nauk SSSR, ser. geol., no. 6, 1954 g.

FIGURE 1. Impressions of brachiopods composed of talc-chlorite material in rock of the same composition.

FIGURE 2. Impression of crinoid composed of talc-chlorite material in rock of the same composition.

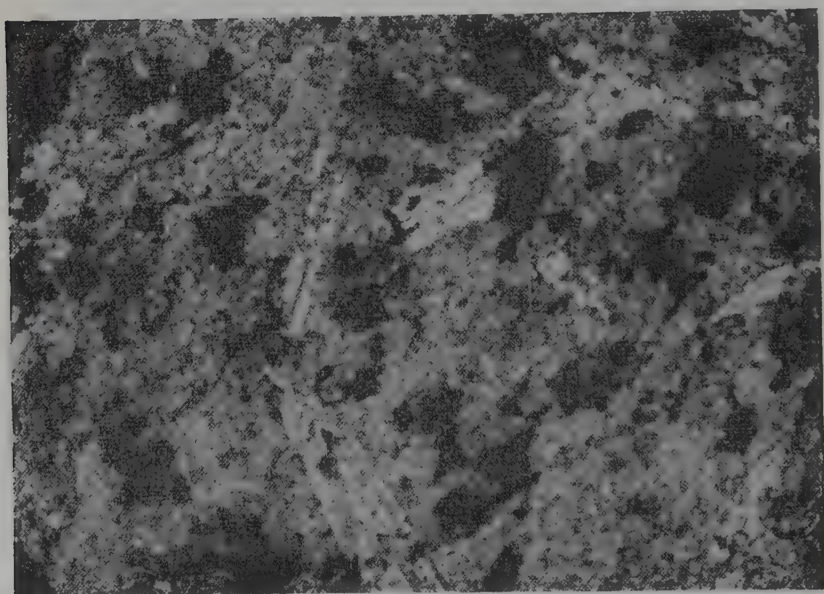

FIGURE 3. Talc-chlorite rock containing much tremolite and iron hydroxide in a bed identified by reference to fossils; 70x, crossed nicols.

Postoyev performed the mineralogic and petrologic examination. The rock is composed mainly of a random aggregate of leaves of talc 0.02 to 0.15 mm long and very narrow. There are isolated small nodules and spots of chlorite, which has been partly converted to talc. Columnar structures consisting of tremolite are common; the tremolite is commonly deformed and replaced by talc. Sphene and hydroxides of iron are present (Figure 1).

No final conclusions can be drawn as to the origin of the deposit; the results are only preliminary and require much amplification in detail.

We are indebted to M. A. Rzhonsnitskaya for

identifying the fossils very quickly and to S. S. Kuznetsov for great assistance in that identification.

Institute of the Geology of Ore Deposits,
Petrography, Mineralogy, and Geochemistry,
Academy of Sciences of the
U. S. S. R., Moscow

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GEOTHERMAL CONDITIONS IN THE ARTESIAN BASIN OF WESTERN TURKMENIA IN RELATION TO THE GEOLOGY OF OIL AND WATER[4]

by

S. S. Dzhibuti

A study was made of the thermal conditions in the water associated with oil in the oil-bearing region of western Turkmenia between 1957 and 1959; this work was a joint enterprise of the Laboratory of Hydrogeologic Problems (Academy of Sciences), the Southern Joint Geologic Expedition (from the Institute of the Geology and Development of Fossil Fuels, Academy of Sciences), and the Turkmen Branch of the All-Union Petroleum Institute.

There are many thermal springs in the part of the western Turkmenia artesian basin near the Caspian [5], and there are many mud volcanoes having associated signs of oil; these have long attracted attention, but the general geothermal and hydrogeologic study of the basin has been divorced from practical needs. This has impeded the search for new oil fields, for this exploration work must go hand in hand with regional geothermal, geochemical, and hydrogeologic studies.

The geothermal conditions in any region are governed by structural features, of which the main ones in this basin are as follows.

The structure is made up in part of Mesozoic-Cenozoic marine, lagoon, and continental sediments, which vary in facies within sections and from one area to another. The oldest rocks are exposed in the Bol'shoy Balkhan uplift to the north of the western Turkmen lowlands, in the Malyi Balkhan uplift to the northeast, and in the Kopet Dag uplift (part in the U. S. S. R.) to the east. The Mesozoic strata within the lowlands are covered by Pliocene and more recent strata as much as 5 km thick. The surface is composed of terraces of deposits from the Caspian and in many places is covered with sand ridges and barchans. Takyrs and salt pans are common. The lowlands form part of an extensive region of Alpine folding, in which regional Cenozoic strata are abundant and which has a complex underlying structure. Geophysical and geologic studies enable us to distinguish six tectonic zones, each with its own history. The Balkhan and Keymir-Chikishlyar zones of uplift have been examined most closely in terms of hydrogeology and geothermal conditions. Regional faults can be traced in these zones; they are associated with anticlinal uplifts, mud volcanoes, and so on. The uplifts themselves have many faults; the structures are largely cut up into blocks. The cores of the uplifts consist of red beds (Middle Pliocene), which are exposed in places (Cheleken, Monzhukly, Boya Dag) as a result of tectonic movements. The roots of the volcanoes stretch down to the Cretaceous, and perhaps beyond, according to studies of the breccias. Springs varying in salt content and temperature occur around the mud volcanoes and around many of the uplifts; these show active signs of oil leakage.

The artesian basin is part of the south Caspian basin, being a division (second-order part) of the latter. The main regions now giving rise to the head of water are the mountain areas of Kopet Dag and Elburz, where Lower and Upper Cretaceous carbonates and sandstones have been raised to considerable heights and have been extensively fractured; these provide good conditions for infiltration and migration. The Cretaceous strata in the lowlands lie under thick Cenozoic beds, and here we find the artesian horizons. Major outflows occur in regions where tectonic movements have produced many fractures, as within the uplifts of the Balkhan zone and along the overthrust (thermal) line of Kopet Dag. Smaller flows occur via the mud volcanoes of the southern part of the east Caspian area.

Water in the lower dynamic zone (the zone of impaired exchange) occurs in all the Pliocene (and more recent) strata that have been bored in the plains of the western Turkmenian depression. The chemical composition of samples from this zone fall into two main groups. The first is of Cl-Na-Ca type; water of this type occurs mainly in the upper parts, but they are found at the lower levels as well as at the edges of anticlines. Their content of dissolved solids ranges up to 300 gm/liter; the ions do not include bicarbonate and sulfate. The second is the Cl-HCO_3-Na type, which occurs in the lower parts, though in places waters of this type have migrated to higher levels along major faults. The dissolved solids range up to 50 gm/liter; sulfates are present.

[4] Geotermicheskiye usloviya Zapadnovo-Turkmenskogo Artezianskovo basseyna (Primenitel'no k resheniyu nekotorykh voprosov gidrogeologii i neftegazonosnosti), (pp. 95-100).

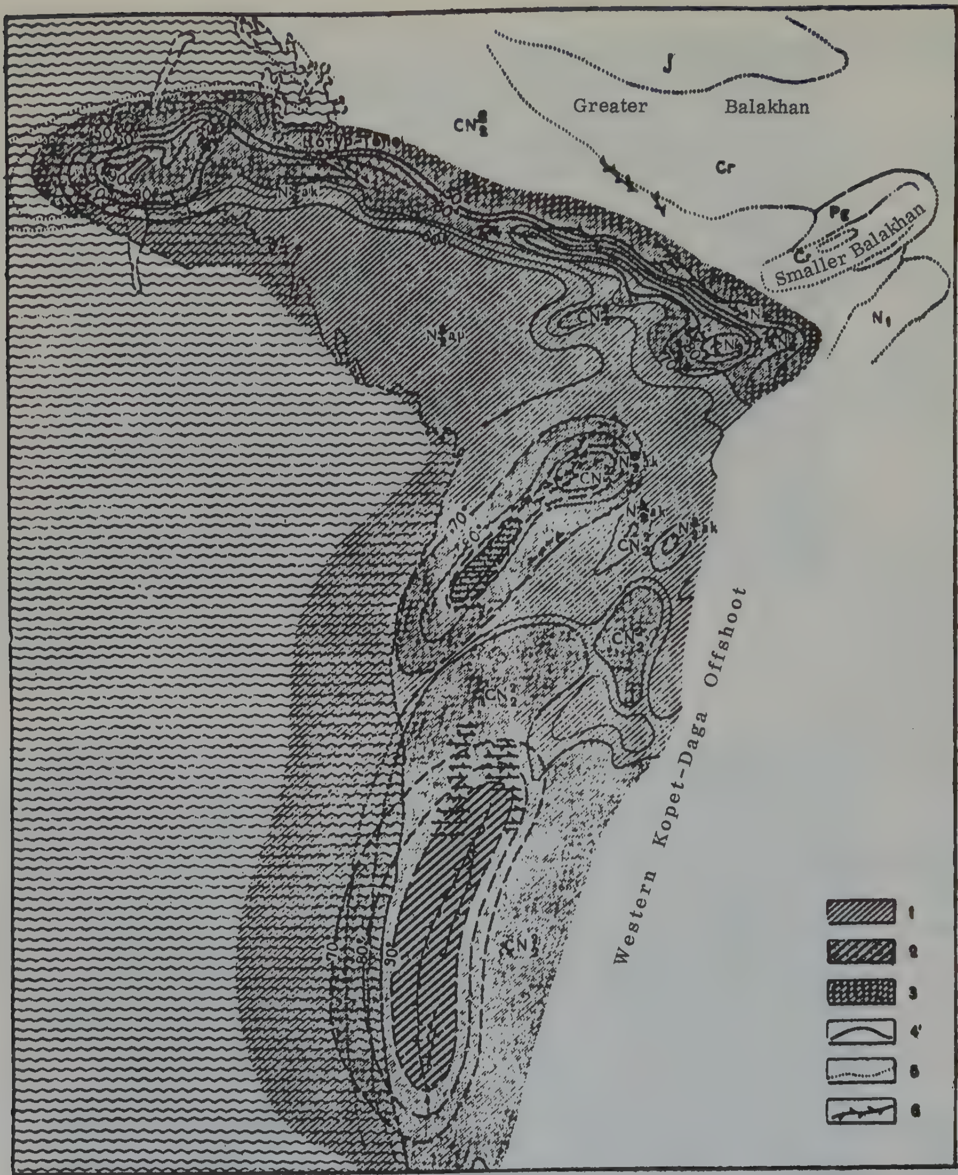

FIGURE 1. Geotherms for the western Turkmenian oil-bearing basin at 2000 m below sea level

1 - Zones of Cl-Na-Ca water of high total dissolved solids at a depth of 2000 m; 2 - zones of rising Cl-HCO_3-Na water of high temperature (geothermal anomalies); 3 - zones of mixed Cl-Na-Ca and Cl-HCO_3-Na water, temperatures and total salt content varied; 4 - isotherms; 5 - boundaries of eroded areas; 6 - lines and zones of main faults.
Compiled by S.S. Dzhibuti on the basis of a geologic section for the structure of the Caspian lowlands at this depth and from stratigraphically identified seismic horizons as given by S. Chamo, T.A. Kharikov, and N.N. Vozhzhova from Yu.N. Godin's results of 1957. Results from boreholes drilled around Kamyshidzha and Okarem in 1958-9 have been included in compiling the geologic section.
Results from boreholes drilled around Kamyshidzha and Okarem in 1958-9 have been included in compiling the geologic section.

Both types contain dissolved hydrocarbons, mainly alkanes.

Temperature measurements in springs and boreholes over oil-bearing structures enable us to relate some geothermal features to the hydrogeology of the region. The mean geothermal gradient varies widely from point to point and within the section, being highest in structures associated with large outflows (Cheleken, Boya Dag; average 26 m/deg) and lowest in buried or partly buried structures (Kizyl Kum, Kotus Tepe, Kobek; up to 50 m/deg). The gradient has a tendency to increase upwards, which we relate to the structure and hydrogeology of the region (the conducting capacity of the disjunctive faults increases with depth). This means that the fall in water temperature per unit distance increases as we pass upwards. The temperature in a borehole as a function of depth is sometimes described by $t = ax + b[1 - \exp(-qz)]$ and sometimes by $t = ax + b$; the first (convex) form occurs in boreholes much heated by rising hot water, which produces local positive anomalies (Cheleken). A similar behavior is observed for boreholes in which adiabatic expansion of hydrocarbon gases produces local negative anomalies (Kizyl Kum). The second (linear) relation occurs for boreholes having almost the natural gradient.

Figure 1 shows the temperature distribution for a depth of 2 km; the geologic section for this depth reveals two structural ridges, of which the northern (Balkhan) one is nearly latitudinal in direction, while the southern (Keymir-Okarem-Kamyshldzha) is nearly meridional. Areas showing thermal anomalies are evident; the largest positive ones occur around the Cheleken oil-bearing structure and in the extensive mud-volcano area in the extreme southwestern part of the area around the southern ridge. Relatively low temperatures occur around the gas-condensation structures of Kizyl Kum.

These anomalies show a correlation with the type of water; the hottest parts have water of the second type ($Cl-HCO_3-Na$; not very saline), while the coolest ones have water of the first type. Intermediate parts have both types of water. Various sources of heat are responsible for the anomalies, which can be large; the ones that can occur here are radioactive decay, metabolism of anaerobic bacteria, and chemical reactions in petroleum deposits (hydrogenation, polymerization, and so on). Rough calculations show that radioactive decay is a negligible source for this region, while the others are minor ones (any other result would imply major anomalies within and around the oil deposits). The main source is then the general one, namely the internal heat of the earth, which is transported by circulating water and, to a smaller extent, by thermal conduction.

Geothermal and hydrochemical charts indicate that the main agent that affects the temperature distribution is the hot water of the second type, which migrates upwards along faults from the Mesozoic strata. At points of outflow (surface or underground) it produces local anomalies (geothermal domes) [4].

The geothermal features confirm Bortsevskiy's [1] conclusion that the water circulates underground and that the water head falls off towards the surface. The water in the Middle Pliocene red beds has a high hydrostatic pressure, for these beds are nowhere exposed at a high level. Further, the water of the first type in the upper parts of the section is being displaced by water of the second type from lower down. This hot water is introduced directly around large faults, and this causes positive anomalies; elsewhere it gives rise merely to a gradual increase in temperature with depth. Vertical migration of liquid and gaseous hydrocarbons has been assumed to be possible at various times [2, 3, 6]; the idea is confirmed by the association of $Cl-HCO_3-Na$ water and high pressures with large faults and mud volcanoes (whose roots extend down to the Mesozoic strata) and by the presence of hydrocarbons in this water. For this reason we may assume the oil and gas deposits of this artesian basin to be secondary; they occur in strata of Pliocene more recent age.

The above results indicate that geothermal measurements provide one of the techniques of assistance in surveys for oil and gas.

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Laboratory of Hydrogeologic Problems
Academy of Sciences of the U. S. S. R.
Moscow

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GORSHKOV'S PAPER ON SOME ASPECTS OF THE THEORY OF VULCANISM[1]

by

Ye. K. Markhinin, and O. M. Alypova

This paper appeared in issue No. 11 of this journal, 1958; it was one of a series on the "determination" of the depth, shape, size, and elastic constants of the material at the magmatic focus of the Kluchi volcano. However, Gorshkov does not restrict himself to "solving" these problems in this paper; he uses his "determinations" of the depth to solve other problems. He "demonstrates" that there are no peripheral (minor) volcanic foci and "solves" the problem of the mechanism of formation of the caldera.

The need to consider this paper nearly two years after it appeared is caused by the fact that some geologists have used his "determination" of the depth of the focus as if it were an established fact. Some even refer to it in discussions of genetic relations between ore deposits and volcanic foci for particular cases; e. g., S. N. Ivanov in "Discussion of some current aspects of the formation of the pyrite deposits of the Ural".[2] This is not the only example, either.

We must first examine whether he did actually determine what he claims to have determined, and also what basis he had for his determinations.

His papers on the depth are based on a comparison of the seismograms for some earth tremors in southern Japan (epicenter distances 24 to 50°) as recorded at the Kamchatka Volcanologic Station with others recorded at Magadan and Petropavlovsk. He concludes that there is no onset (or at least a very much delayed onset) of the S waves at Kluchi, while the recordings elsewhere are normal; this feature he ascribes to a liquid magmatic focus under the Kluchi volcano, which blocks out these waves. He takes an assumed angle of emergence for the S waves to determine the depth of the focus; the transverse size of the focus is deduced from the boundaries of the seismic shadow. The "secondary waves" on the Kluchi seismogram he takes to be compression waves altered by refraction at the focus, and so from their speeds he "determines" the elastic constants of the material.

Unfortunately, all these determination are based on unreliable data, as the following points show.

1. In these papers he gives as confirmation for his calculations and arguments only the results for the Japanese earthquake of November 27, 1953, whereas many tremors must be considered in order to determine the laws governing seismic waves.

2. He fails to give exact results even for this one tremor for the coordinates, depth of focus, and time at focus.

3. Most of the tremors that he might have considered are comparatively weak ($M \leqslant 5.5$), so many of the waves are very weak on the recordings and do not show sharp onsets. The exact time of arrival of the S waves cannot be determined for most of them. Moreover, he neglects the differences in the level of microseismic noise and in the scale of the recordings in his comparisons of Kluchi with Magadan. The amplitude of the microseisms for horizontal waves at Kluchi is 5 to 10 times that at Magadan for most cases, while the seismograms at Magadan are recorded with mugh greater magnification. For example, the magnifications were respectively 250 and 1000 for the earthquake of November 27, 1953. This shows why the onset of the S waves was clear at Magadan whereas the weak S waves at Kluchi were obscured by strong microseisms. He takes the later and stronger parts of the S waves as a

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[1] O stat'ye G. C. Gorshkora "Nekotorye voprosy teorii vulkanologii", (pp. 101-103).

[2] Trudy Gorno-geologicheskogo instituta Ural'skogo filiala Akad. Nauk S.S.S.R., vyp. 43, 1959 (Transactions of the Geological Institute of the Ural Branch, Academy of Sciences of the U.S.S.R.).

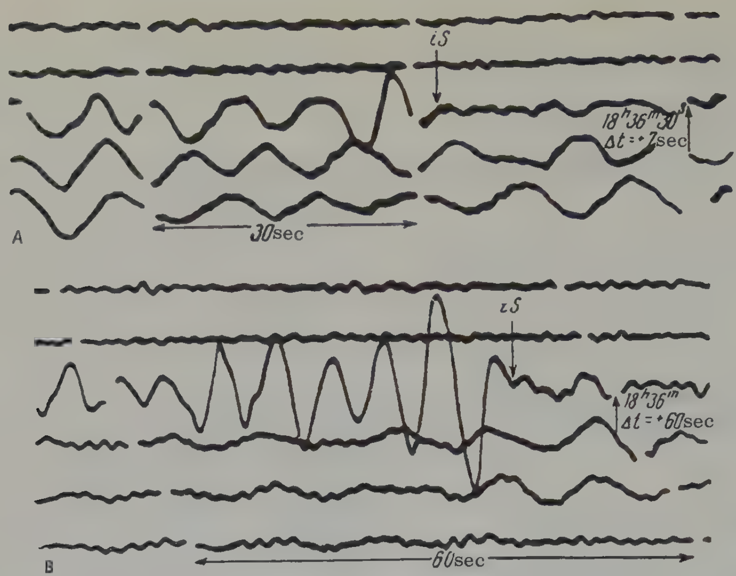

FIGURE 1. Onset of the IS wave for the earthquake of June 30, 1958; component B-3;

A - at Kluchi, working magnification 300X; B - at Magadan, working magnification 1000X.

delayed onset of those waves. Sometimes these later onsets may be those of sS waves (ones reflected near the epicenter), which are often seen in recordings for earthquakes in the Far East.

The stronger earthquake of June 30, 1958 (M ≈ 6) in southern Japan (see Figure 1 and Table 1) occurred at a time when the microseisms at Kluchi were weak relative to the S waves;here there is clearly no special feature in the time of arrival at Kluchi, although Gorshkov would have us believe that the S waves should be screened off.

4. The recordings for earthquakes in southern Japan show that in every case when there is an onset of a new wave 10 to 19 seconds after the arrival of the P waves at Kluchi there is a similar onset at the other two stations; this is clearly visible for those of November 27, 1953 (Gorshkov reproduces these in his papers). These onsets cannot correspond to waves refracted by the focus; the waves arriving 10 to 19 seconds after the P waves are sP waves (ones reflected near the epicenter).

These features show that we have no proof that the S waves are screened off at all by the focus; what is more, we cannot use something that has not been proved to make quantitative estimates of the depth, size and elastic constants of the focus. Incredible as it may seem, he goes even beyond this and asserts that his

Table 1

Data on the Earthquake of June 30, 1958 in southern Japan. Time at Focus 18. 26. 22: Coordinates of Epicenter $\varphi = 31°$N, $\lambda = 141.5°$E. Strength 6.

Station	Azimuth	Epicenter distance[1] Δ	Time of onset	Transit time	Time calculated from Jeffries-Bullen hodograph	Deviation from calculated time, sec
Kluchi	215°	28,7°	eP 18 32 17 iS 18 37 04	tp 5 55 ts 10 42	tp 5—56 ts 10—41	Δ tp—1 Δ ts +1
Magadan	204°	29,2°	P 18 32 22 iS 18 37 13	tp 6 00 ts 10 51	tp 6—01 ts 10—50	Δ tp—1 Δ ts+1

[1]Calculated from the coordinates of epicenter and station.

onclusions as to the depth and so on "are sufcient to serve as a basis for a brief discussion f some general aspects of volcanology". His merity is especially great in "solving" the roblems of peripheral foci and of the origin of e calders. He considers that his "observed" creen lies at a depth of 50 to 70 km, no other creens being found at other depths, and that eripheral foci are absent; he asserts that "this eduction should be of general significance". e ignores entirely the extensive evidence on e shape, size, and depth of volcanic foci, hich includes some geophysical evidence that agmatic foci that feed directly into the central olcano lie at no great depth.

Having disposed of peripheral foci, he rects without hesitation the generally accepted ew that any large calders is formed by the ollapse of the roof of a magmatic focus, alough this has repeatedly been convincingly emonstrated (Vlodavets, Williams, Tonakodate, an Bemmelen, and so on). He is forced to rert to the older view that a caldera is formed the collapse of the walls of a channel, a echanism now accepted only for certain small lderas.

Geophysical studies in this country are going rough a period of rapid expansion; very soon ey should give valuable results and exact data, hich should enable us to obtain a better conption of the deeper structures in volcanoes. particular, seismic studies on the Kluchi volno will be extended, and a searching examinaon will be made of the passage of seismic ives through the Kurile-Kamchatka volcanic ain.

We consider Gorshkovs paper to be an exmple of how not to use geophysical results in lving important geologic problems.

Received, 17 September 1960

LETTER TO THE EDITOR[3]

by

V. I. Smirnov, T. Ya. Goncharova

In issue No. 3, 1961, papers by V. V. iridov and R. P. Tuzikov contain comments on our paper on the geologic features of the formation of pyrite deposits of the western part of the North Caucasus (No. 2, 1960). Our reply to those comments is as follows.

We gave facts and deductions that indiate that the pyrite deposits of the Paleozoic greenstone belt of the North Caucasus were formed near the surface at the same time as the submarine volcanic rocks; some of the lodes may have been derived from mineralizing solutions associated with metasomatism in these rocks, while others (especially the Glavnoye orebody at Urup) may be of subvolcanic sedimentary origin.

This indicates that Svidorov's evidence (that some orebodies in the Urup group are associated with volcanic rocks) is in no way in conflict with our ideas on the genesis; nor is the evidence of alteration in the host rocks or of metasomatism on the under side of the Glavnoye orebody. Svidirov quotes results from recent widely spaced survey boreholes and casts doubt on earlier ideas on the geologic structure and position of some pyrite lodes in the Urup deposits. This discussion relates to minor orebodies, whereas there is no doubt as to the position of the Glavnoye (Main) orebody, which was the one discussed in our paper. This is to be expected, for we used Snezhko's stratigraphic scheme for the Urup region, which is one he is closely acquainted with; he compiled it during detailed geologic mapping of the igneous rocks and correlated it closely with sections between the Malka River and the Malaya Laba River as given by the most recent workers (D. S. Kizeval'ter, S. M. Kropachev, and so on).

The remarks by Tuzikov (geologist to the Institute of Balneology, Ministry of Health of the R. S. F. S. R.) take no account of the distinctive details pointed out above in relation to the formation of these pyrite lodes, although we have tried to explain them to him by letter and by word of mouth. He remarks on the changes in the country rocks around the handing side of the Glavnoye orebody at Urup, but it is still necessary to demonstrate that they occurred at the same time as the formation of the pyrite deposits.

That is, the facts quoted by Sviridov and Tuzikov do not conflict with our conception of the origin of the pyrite deposits at Urup or elsewhere in the North Caucasus.

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[3] Pis'mo v pedaktsiyu.

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CHRONICLE

CONFERENCE ON DEEP SEISMIC SURVEYS[1]

by

I. A. Rezanov

This conference was held on November 14-19, 1960 in Moscow at the Institute of Earth Physics by that institute in collaboration with the Council on Survey Geophysics (Academy of Sciences) and the Geophysics Division of the Ministry of Geology and Conservation of Resources. The conference was concerned with a 10-year survey of work on deep seismic surveys (D. S. S.) in the U. S. S. R. The main papers were given by the staff of the Institute and by workers from the All-Union Geophysics Research Institute of the Ministry. Some 19 other organizations are also performing D. S. S.

D. S. S. methods have been used in many parts of the U. S. S. R. ; e. g. , on ancient platforms and shields (Karelia, Ukraine, Bashkiria), on young platforms (Kara Kum, central Kazakhstan, West Siberian lowlands), in downwarps near or between mountains (Fergana depression, Kopet Dag downwarp, Kura depression), in high mountains (Tien Shan, Pamirs), in regions of Mesozoic folding (Magadan to Kolyma), around land-locked seas (Black Sea, Caspian), and in the transition region between the continent of Asia and the Pacific Ocean (Sea of Okhotsk, Kurile Islands, and adjacent parts of the Pacific). A start on D. S. S. was made in 1960 in the Caucasus.

The amount of detail in the surveys varies, and so some schemes for sections of the crust are more reliable than others. The most detailed surveys have been made in Karelia, Bashkiria, southeastern Turkmenia, Fergana, and around Bukhara, where continuous profiles have been constructed.

Purposes of the conference were to discuss methods of recording waves from great depths, to elucidate the nature of the waves, to interpret the results, and to choose the best directions for future work. No special emphasis was placed on geologic interpretations, although the new evidence on the deeper structures and on the variation of velocity with depth has cast some light on the structure of the crust generally. The aspects of main interest to geologists are the crustal structure in individual areas and the crustal structure generally, both as deduced by means of D. S. S.

The conference opened with a paper by V. V. Belousov on D. S. S. as a means of solving geologic problems. Most of the papers presented sections and curves for the velocity as a function of depth. A. V. Yegorkin reported on the structure of the crust in the southeastern part of the Russian platform; the velocity curve for the section was deduced from the effective, layer, and boundary velocities as indicated by hodographs for the reflected and head refracted waves. Below the platform cover there lie two thick layers whose boundary velocities are about 6. 0 km/sec (5 to 20 km) and 7. 1 km/sec (20 to 40 km), and within these are bands with higher velocities (6. 6 km/sec at about 10 km, 7. 6 km/sec at 30 km). The sections indicate that the seismic boundaries lie conformably, whereas the Mohorovičić discontinuity does not; higher levels in the last correspond to lower levels in the other boundaries and vice versa. All boundaries dip down towards the Caspian depression. The discontinuity lies at an average depth of 39 km and has a speed of 8. 1 km/sec. Yegorkin's general scheme is thus one of a steady increase in speed with depth, on which are superimposed local increases and decreases within layers.

I. V. Pomorantseva, and M. V. Margotyeva offered a different interpretation of the wave picture for this region. Some waves previously assumed to be head refracted waves (on dynamic and kinematic grounds) were shown to be more probably ones arising in a medium having a velocity gradient (speed increasing downwards). This gives a different picture for the structure, which then has only three or

[1] Soveshchanie po glubinnomu seysmicheskomu zondirovaniyu zemnoy kopy, (pp. 119-122).

four layers each having a speed that increases gradually with depth. The presence of thin layers of higher speed is considered to be unlikely.

B. S. and I. S. Vol'vovskiy reported on the Fergana depression and the Bukhara-Khiva zone; the wave picture is complex. The recordings for the one area differ rather from those for the other, presumably on account of differences in tectonic position. The sections were published recently in Doklady, Akad. Nauk S. S. S. R. (133, No. 6, and 134, No. 5, 1960); the conclusion is that the most probable structure between the top of the Paleozoic basement and the Mohorovičić discontinuity is that of a medium whose speed increases gradually with depth.

K. E. Fomenko presented a summary of his paper on a profile 250 km long in southeastern Turkmenia from Tedzhen via Bayram Ali to Karabe-kaul (the full paper was not given). The basement has two levels composed of Paleozoic rocks at least 6 km thick and of a folded (presumably Precambrian) lower part at a depth of 9 to 11 km (speed 6. 7 to 6. 8 km/sec). This lower part has two refracting boundaries. Reflected and refracted waves show that the discontinuity lies at 40 to 50 km down; it has an unconformity with the boundaries higher up at the eastern end of the profile, where it dips downward (the other boundaries rise). This serves to explain observed gravitational anomalies (see Izv. Akad. Nauk Turk. S. S. R., No. 4, 1960).

D. N. Kazanli, and A. A. Popov described results for a profile 1000 km long (Balkhash to Petropavlovsk) and for a profile in the Dzhezgazgan region; continuous readings were taken on separate sections of the profiles. The first boundary (5 to 12 km) is interpreted as the top of the lower Paleozoic; it reproduces many surface structures, and its speed is 6. 2 km/sec. The second is the top of the basalt layer (18 to 22 km; speed 6. 8 km/sec) and includes lower Paleozoic and Precambrian complexes together with granite. The third is the Mohorovičić discontinuity (8. 2 km/sec), which lies at depths of 35 to 50 km.

I. V. Litvinenko presented results for a profile 200 km long from Kem to Ukhta in northern Karelia (Baltic shield). The boundaries most clearly detectable are one at 10 to 15 km (surface of basalt; 6. 65 km/sec) and one at 35 to 38 km (Mohorovičić). Others at 5 to 8, 16 to 20, and 25 to 28 km are less certain. There are also fault zones extending right through the crust; these lie at the junctions between distinct structural facies zones and are closely related to stages of volcanism.

B. D. Trebukova reported on work in Azerbaijan; one profile passed through the Talysh-Vandam gravity anomaly, while the other joined the buried side of the Low Caucasus to the foothills on the south side of the High Caucasus. Seismic sections and structure schemes were used to represent major plutonic structures. The least depth for the basement is 5 km; that for the basalt, 7 km. The basement falls rapidly to 12 to 13 km as the High Caucasus is approached; the basalt, to 23 or 24 km. This is probably the result of downfaulting or flexures.

Ya. B. Shvarts, N. I. Davydov, and G. A. Yaroshevskaya gave results for the line from Magadan to Kolyma (area of Mesozoic folding in the northeast). This work was done jointly by the Northeast Geological Survey and the Institute of Earth Physics. At depths down to 7 km (near Kolyma) and 4 km (Okhotsk-Kolyma divide) there is a layer of sediments (mean speed 5. 3 km/sec), which belongs to the Verkhoyansk complex. Below this there is a so-called granite layer (boundary speed 6. 0 km/sec), and at 20-22 km there lies the "basalt" layer (boundary speed 6. 7 km/sec, mean speed 5. 8 km/sec). At the southern end (some 100 km from Kolyma) the surface of the basalt rises rapidly to 12 or 14 km; the Mohorovičić discontinuity lies at 38 km in the north and 34 km in the south.

I. P. Kosminskaya (on behalf of several others) described numerous studies on the margin of the Pacific (Sea of Okhotsk, Kurile Ridge, Pacific Ocean), with special emphasis on analysis of the dynamic features of the wave groups; continental, oceanic, and intermediate types of section were distinguished. The continental type covers depths down to 20 or 30 km having granite-basalt or granite velocities; the oceanic type, to thin crusts (10 to 12 km) with water and basalt velocities; and the intermediate type, to crusts 14 to 20 km thick with sediments and basalt velocities. The results reveal minor differences in the seismic boundaries; these require a special study. A complete section was given for the crust from the Kolyma via the Okhotsk-Kolyma divide, Sea of Okhotsk, and the Kuriles, to the Pacific; this illustrates sections of all the above types.

Several papers dealt with material already published (studies on the Tien Shan, Pamirs, western Turkmenia, Black Sea, Caspian); others gave only preliminary results for northwestern Turkmenia, the Ukrainian massif, and the West Siberian lowlands. A few papers dealt with the wave patterns given by earthquakes and large explosions.

Much interest was aroused by a paper from the Institute of Mathematics (by A. S. Alekseyev) on the kinematic and dynamic features of the principal waves for several theoretical models of the crust. It was deduced that the crust has vertical velocity gradients.

The numerous new results, especially for the Russian platform and Central Asia, have required a revision ot ideas on the wave patterns and on the velocity distribution within the crust. Reflected waves give the main (layer) velocity for each layer; this is usually less than the boundary velocity as deduced from refracted waves, which indicates that the crust consists of a sequence of fairly thin layers differing in velocity, and this would mean that the mean velocity is lower than the speed for some particular high-velocity layer at which the refraction occurs. This was Yegorkin's treatment for the Russian platform (two thin high-velocity layers), but recent work has shown that another explanation may be more probable in some situations. The conclusion drawn at the conference was that some of the waves previously considered as head refracted waves are more probably ones refracted in media having velocity gradients.

Recent seismic studies have shown that the crust has far more layers than the traditional two (neglecting the sediment cover). Two "granite" layers have been demonstrated for Central Kazakhstan, and two basalt ones for the Russian platform, for Fergana, and for western Turkmenia. Even though only two layers can be demonstrated with certainty in some places (as in Karelia), three sharp seismic boundaries can be demonstrated. Sometimes (as in eastern Turkmenia and in Bashkiria) the Mohorovičiá deiscontinuity has an unconformity with all seismic boundaries above it; this means that these boundaries differ in nature from the Mohorovičić discontinuity. Yu. N. Godin supposes that the entire crust down to the discontinuity should be included in the basalt layer, which is composed of various metamorphic rocks. The seismic boundaries are then interfaces between structural stages differing in age. This is my view also, although the view is open to certain objections. It has been doubted whether the boundary between two structural stages should appear so clearly in the velocity section; moreover, it is not clear why the lower boundaries should be almost horizontal when we find large variations in depth for structures near the surface.

The discussion revealed that new ideas are developing on the structure of the crust, and the decision now rests not so much with geophysicists as with geologists. The problem is now as to which structure model is geologically best, for metamorphism and metasomatic processes may alter rocks to varying extents (the wave speed and the density are the main features here). The problems remain ones for discussion, but it is already clear that the traditional granite-basalt model must be abandoned. New dieas cannot develop without a broad discussion between geochemists, petrographers, specialists on the Precambrian, and so on.

One topic much discussed at the conference was the amount of detail needed in these surveys; the general view was that very detailed studies are required in regions of simple tectonic structure while the nature of the waves remains uncertain. Less detailed but cheaper methods will be justified only when considerable progress has been made.

It was universally agreed that the method cannot be simplified to a determination of the two most obvious boundaries (the top of the basement and the Mohorovičić discontinuity). The main task is that of distinguishing boundaries within the crust, although this requires very detailed work, for which methods are not yet fully worked out.

A future problem is that of detailed study of the layers below the Mohorovičić discontinuity.

Organizational topics included a suggestion that the Ministry should set up an Interdepartmental Commission, whose tasks should include that of coordinating all seismic and other work on the deeper parts of the crust. The commission should be charged with drawing up a plan of immediate tasks for the next 7 or 8 years. A special group should be set up to survey D. S. S. results and to publish in the next two or three years a book under the title "Structure of the Crust in the U. S. S. R. from D. S. S."; this group should also perform a number of special surveys on methods in order to advance the technique of D. S. S. on land and sea. There should be a special conference on the geologic interpretation of D. S. S. results.

CONFERENCE ON PHYSICAL METHODS OF EXAMINING SEDIMENTS AND MINERALS[2]

by

N. V. Logvinenko, and V. D. Shutov

This conference was hled on December 26-29, 1960 in the Geological Institute of the Academy; it was organized by the Commission on Sediments of the Division of Geologic and Geographic Sciences.

There were about 400 participants numbered and were drawn from 50 cities; they represented 129 research and production organizations. The great interest shown by lithologists and mineralogists is the result of the need for advances in methods in order to provide early solutions

[2]Soveshchanie po fizicheskim metodam issledovaniya osadochnykh porod i mineralov, (pp. 122-124).

to many pressing problems. The work of the conference illustrates the view ("Pravda", 31 December 1960) of the President of the Academy, A. N. Nesmeyanov, that "Methods are very important, sometimes decisive, in science; new methods and new ideas from other branches of science can infuse new blood into an apparently settled and established branch".

A short introduction by Academician N. M. Strakhov (President of the Commission) was followed by the presentation of 35 papers, which dealt with many general aspects of lithology and with recent advances in the application of physical methods to sediments and minerals. The introductory paper by A. G. Kossovskaya, V. D. Shutov, and M. Ya. Kats (Geological Institute, Academy of Sciences) showed that the main trend in work on methods should be directed to elucidating the formation of sedimentary minerals at all stages from deposition to metamorphism. A necessary step here is the accumulation of data on the structural features and physical properties (electrical, magnetic, mechanical) of authigenic minerals. Here mean values will not suffice; full statistical parameters are needed. This information should reveal the features of minerals formed under various thermodynamic conditions and thus should reveal the specific aspects of sedimentary minerals. The results will be of considerable value in deciding the origins of deposits of doubtful genesis. An essential requirement here is to introduce new methods (mainly physical) in the stages of preparation (rock disintegration, separation of minerals) and also in the subsequent mineralogic and physical examination of the minerals. Both aspects require new apparatus and techniques which should be derived and adapted from physics and chemistry.

M. F. Vikulova (All-Union Geological Research Institute) gave a general survey of the various physical methods that have been used in identifying rocks and minerals in finely divided form; she stressed the special value of X-ray methods as being the most universal and reliable for all clay formations.

E. V. Rozhkova (All-Union Mineral Resources Institute) dealt with the general genetic interpretation of changes in the physical constants (especially the dielectric constant) of minerals; jointly with K. S. Ershova and O. V. Shcherbak she reported on an improved series of instruments (developed at the institute) for use in dielectric separation of minerals.

A group of papers on methods of disintegrating and separating sediments and minerals followed. V. D. Shutov, M. Ya. Kats, and V. V. Baranov (Geological Institute, Academy of Sciences) described an ultrasonic method of disintegrating hard rocks; this was developed in the Laboratory of Authigenic Mineralogy. It has been found possible to disperse finely divided rocks and minerals in this way for the purposes of electron microscopy. A demonstration was given of the removal of weathered surfaces, adhering material, and so on, by means of ultrasonics. L. A. Sergeyev and A. M. Medvedova (Institute of the Geology of Fossil Fuels) described the use of ultrasonics in isolating spores and pollen from rocks. Y. I. Muravyev (Geological Institute) described the disintegration of carbonate rocks by electrodialysis in a current of CO_2. M. Ya. Kats, P. P. Reznikov, and V. I. Baranov (Geological Institute) described a new isodynamic electromagnetic separator constructed in the institute; this can separate clay minerals in suspension as well as dry grains. K. K. Nikitin and N. V. Tarakanova (Institute of the Geology of Mineral Deposits, Academy of Sciences) described experience with the new model of the TBÉS-6000 electrical) separator. Electrical separation was shown to be especially desirable for nonmagnetic materials of specific gravity above 4.15 and for certain diamagnetic minerals differing very little in specific gravity. The paper by N. V. Logvinenko and A. A. Lazarenko (Kharkov University) on separation of clay minerals by electrophoresis aroused much interest. Simple methods and apparatus have been used in the Department of Petrography to economize very greatly in the time required to collect the colloidal fraction of sediments. G. A. Kots (All-Union Mineral Resources Institute) described a miniature dressing laboratory for mineralogic studies of rocks and ores. This is fitted with miniature separators (electrical, magnetic, flotation, and gravimetric) suitable for use in the laboratory and in the field.

Another group of papers dealt with methods of measuring physical and physicochemical properties. M. K. Kalinko (All-Union Oil Prospecting Research Institute) described some improvements in methods of determining the porosity, permeability, and total carbonate content of rocks. The paper by A. I. Krimara (Geological Institute, Kazan Branch of the Academy of Sciences) on a new method and apparatus for porosity and permeability measurements was heard with considerable interest. A joint paper from the Arctic Geology Research Institute and the All-Union Drilling Research Institute (authors A. T. Marmorshteyn, I. M. Petukhov, B. E. Nersesyants, and G. I. Morozov) dealt with an interesting new method of measuring the electrical conductivity of a rock under pressure. It was demonstrated that the total porosity and the composition of the ground mass affect the conductivity. V. I. Muravyev (Geological Institute, Academy of Sciences) and Ts. M. Raytburd (All-Union Institute of Hydrogeology and Engineering Geology) jointly described a new method of determining the degree of orientation of the clay minerals in natural specimens of clay rocks.

S. A. Toporets (Laboratory of Coal Geology, Academy of Sciences) reported on methods of measuring the electrical parameters of coal; the resistivity was shown to be a function of the ash content and of the degree of alteration.

A series of papers dealt with methods of measuring the physical properties of minerals; of these the most interesting were those on the measurement of density with high precision (M. Ya. Kats, Geological Institute, Academy of Sciences), on the magnetic parameters of carbonates (V. M. Vinokurov, Kazan University), on the thermal electromagnetic force of crystals of galena (G. A. Gorbatov, All-Union Mineral Resources Institute), and on the Magnetic susceptibilities of minerals (K. K. Nikitin and G. L. Adyan, Institute of Geology of Mineral Deposits, Academy of Sciences of the U. S. S. R.). All papers, especially Gorbatov's, stressed the need for a proper study of the statistical distribution of the constants in order to reveal type properties and structural features that are correlated with the conditions of formation. Special attention was devoted to novel items of equipment. Kats described a gradient tube, which provides a continuously varying density covering one-tenth of the full range available from the standard heavy liquids. The method has been used to make density measurements to 0. 003 or 0. 005 simultaneously on 500 to 1000 grains. V. M. Vinokurov has used E. S. R. in conjunction with static magnetic measurements to elucidate the position of paramagnetic ions in carbonates and, in particular, to assay for iron and manganese. K. K. Nikitin and G. L. Adyan have measured magnetic susceptibilities by means of weighing in a homogeneous field; the results show that the conditions of formation have a great effect on the magnetic parameters of a mineral. Other interesting papers in this section were one by A. A. Ozol (Kazan University) on the adsorption of cations by clay colloids as studied by E. S. R. methods, and one by V. N. Karyukina (All-Union Mineral Resources Institute) on a new microcrystalloscopic method of determining certain cations and anions in minerals.

The most interesting of the papers on thermal analysis was that by V. I. Ivanova (All-Union Geological Research Institute). A new apparatus for microanalyses by the rate method was demonstrated.

The main papers on structure analysis were a survey by B. B. Zvyagin (All-Union Geological Research Institute) electron-diffraction study of layered minerals of many years duration, a paper by V. A. Frank-Kamenetskiy (Leningrad University) in clay formations generally and on sedimentary minerals of carcase structure in particular as examined by X-ray methods, and a paper from the geological Institute (A. G. Kossovskaya, T. V. Dolmatova, and V. V. Aleksandrova) on methods of examining mixed layered structures in clay minerals. These were shown to be important to an understanding of alterations in clay following deposition; a method was presented for deriving the structures by reference to high-order basal reflections.

The conference adopted a resolution, in which were formulated the most important tasks in the general development of methods and in the introduction of particular methods. Several instruments whose development had been completed were suggested for commercial production.

After the conference the participants were shown the work of the Authigenic Laboratory of the Geological Institute and also some laboratories of the Institute of the Geology of Ore Deposits, Petrography, Mineralogy, and Geochemistry.

SECOND FERSMAN LECTURES[3]

This series of lectures was held under the auspices of the Division of Geographic and Geologic Sciences of the Academy on December 21, 1960.

An introduction by Academician D. I. Shcherbakov, secretary of the Division, was followed by a paper by Associate Member A. A. Sankov on "Evolution of Element Migration in Geological Time" (see the first paper in this issue).

Associate Member A. V. Siderenko reported on the work of the Kola branch of the Academy in the past 30 years; this branch is associated with the Kola Base of the Academy, which was set up in 1930 on the initiative of A. E. Fersman in order to study the mineral resources of the Kola peninsula. Fersman' ideas on these resources have been extensively reflected in the work of the branch.

GENERAL CONFERENCE OF THE DIVISION OF GEOLOGIC AND GEOGRAPHIC SCIENCES, ACADEMY OF SCIENCES OF THE U. S. S. R., FEBRUARY 1 AND 2, 1961[4]

The conference, which was held in Moscow, opened with an address by the secretary of the Division, Academician D. I. Shcherbakov. His

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[3] Vtoroe chtenie imeni A.E. Fersmana, (p. 125).
[4] Obshchee sobranie otdeleniya geologo-geograficheskikh nauk Akad. Nauk S.S.S.R., 1-2 Febralya 1961 g, (pp. 125-127).

address dealt with the activities of the organizations in the Division. The ghree main lines of work conducted are 1) research within the division, 2) collaboration in the plan for the development of science, and 3) collaboration in international research projects.

1. The scientific work has been better organized than in previous years, and there has been closer collaboration with other organizations. Papers and other publications in preparation at the time of the conference numbered 178, and 156 appeared during the period.

Further progress was made during 1960 in various aspects of the distribution of mineral resources, with emphasis on the laws of occurrence as providing a basis for exploration; notable results have been produced. For example, it has been found that mineralization not giving rise to ores is associated with acid-base differentiation in magmatic solutions, as is mineralization giving rise to common hydrothermal ores; mineralization and the distribution of trace elements have been shown to be correlated with tectonics; and maps have been compiled to illustrate the regularities in the distribution of coal seams in the U. S. S. R.

Progress has also been made in methods of compiling tectonic maps (maps have been compiled for Europe, Eurasia, and Africa), and this work has involved a revision of some long-accepted ideas on general tectonics.

Methods have been developed for the stratigraphic subdivision and correlation of Riphean strata; it has been found possible to compare beds from open oceans with those from epicontinental seas.

New results have been obtained on the origin and accumulation of water in the West Siberian and Azov-Kuban artesian basins; a theory has been developed for the processes occurring druing conversion of rocks to the frozen state.

A first draft of an absolute geochronologic scale has been published (in "Izvestiya" No. 10, 1960). A map has been published of the Recent tectonics of the U. S. S. R. (1:5, 000, 000), which is of much value for serial surveys taken from great heights. Volume I of "Mineraly" has appeared; this is the most complete treatise in the world literature and systematically reviews the latest results. Four major monographs on trace elements have been published, as well as many other books.

The report dealt also with some aspects of the earth sciences not considered above; here Shcherbakov emphasized the great importance of Academician A. M. Strakhov's two-volume work "Principles of the theory of Lithogenesis" (Izd. Akad. Nauk S. S. S. R., 1960), which is the result of many years' work on the formation of sedimentary rocks. The same applies to M. F. Neyburg's work on fossil plants from the Permian beds of Angarida, which is of great interest to paleobotanists, paleogeographers, and stratigraphers.

The purely geographic work has included major studies on the Indian Ocean and Mediterranean, as well as the publication of monographs on the physical and economic geography of the U. S. S. R. and of other countries.

2. The Division has worked on the plan for the development of science in close collaboration with the Ministry of Geology and Conservation of Resources of the U. S. S. R. The Division's proposals as to lines of research have been harmonized with the Ministry's requirements for theoretical studies and for further expansion in mineral resources, especially the study of scarce materials.

Collaboration with the state planning organizations enabled the Division to direct plans for research to the more urgent tasks; e. g., conservation and restoration of natural resources (Institute of Geography) and exploration and use of thermal springs (Laboratory of Hydrogeologic Problems).

3. Much benefit was obtained from participation in the work of the 21st Session of the International Geological Congress (Copenhagen), of the 19th Session of the International Geographic Congress (Stockholm), of the 12th Assembly of the International Union of Geodesy and Geophysics (Helsinki), and of the Intergovernmental Conference on Oceanology (Moscow).

Soviet work has made a notable contribution to the compilation of tectonic maps, especially for recent movements. Research on ages of geologic formations had a good reception; this was done in several laboratories of the Division and of the Ministry. This work received recognition in relation to Fennoscandis in the election of Academician A. A. Polkanov as a foreign member of the Geological Society of Sweden.

The papers presented at the 12th Assembly were less fully representative of Soviet work (partly because there are no special geophysical organizations in the Division), but much interest was aroused by the papers on active and extinct volcanoes as well as by those on general volcanology, geothermal research, and geochronology.

Proposals from the Soviet delegation formed the basis of the resolutions adopted by the Intergovernmental Conference. One of these resolutions dealt with the formation by UNESCO of a Permanent Intergovernmental Oceanographic Commission.

Academician Shcherbakov dealt here with the International Indian Ocean Expedition (1960-5), which is designed to assist under-developed countries to explore and exploit the Indian Ocean. The Soviet vessle Vityaj has been participating, and so far this ship has made by far the largest contribution to this work; it has made Major discoveries in relation to bottom relief, to the circulation of ocean currents, to the chemistry of the water, and to the study of marine life.

The Division has organized the 2nd All-Union Session on the Laws of Distribution of Mineral Resources (Kiev), the First All-Union Conference on the Geology and Metallogeny of the Pacific Ore-Bearing Belt (Vladivostok), the Second Session of the Geographic Society (Kiev), and so on.

In past years, the Division's plans covered many topics, and this feature continues; many organizations consider it necessary to concern themselves with all aspects of science, whereas the main task of Academy organizations ought to be to deal with the more urgent aspects of theoretical and applied problems. The number of distinct problems being handled in the future ought to be minimized, which would facilitate more effective formulation of proposals for the economic application of neglected discoveries. The government has requested us to propose for use all major research results likely to be economically valuable but requiring special governmental action. Trivial proposals must be excluded, of course.

Coordination between parts of the Division working on common problems must be improved; for example, the Geological and Geographic Institutes deal with Quarternary geology, the Laboratories of Hydrogeologic Problems and of Volcanology deal with geothermal conditions (as does also the Institute for the Geology and Exploitation of Fossil Fuels. At present, there is no contact between those working on these problems in the various institutes.

In conclusion, Academician Shcherbakov dealt with the development and location of the parts of the Division and replied to some ciriticisms that have been made recently. Some consider that geology has degenerated in recent years and has ceased to be concerned with a general philosophy of nature; moreover; it has not made proper use of modern experimental techniques, especially in physics and chemistry, Shcherbakov's reply is as follows "I stand firmly by the propostion that science generally and individual branches in particular, develop in response to the demands of human society". Methods and solutions alter, but the purpose (satisfaction of human needs) remains unchanged, although the needs themselves alter. All the institutes in the Division were founded since the revolution and have collaborated in the major task of creating a domestic source of mineral raw materials. This is the reason why many of the geologic institutes are concerned with the composition of the crust and with the amounts and location of materials.

Our geologists have done much in this respect, and their work shows satisfactory progress. We do not lag behind in the use of modern methods, although the lack of buildings prevents us from bringing all our equipment up to date; nevertheless, our laboratory facilities are good and are adequate for current requirements. It is true they are rather limited, but steps are being taken to extend them.

There has arisen a need to examine the deeper structures of the earth's crust, especially in relation to magmatic processes, thermal conditions, and differentiation effects. The lower parts of the crust, and perhaps the mantle, may be the source of the forces that determine the development and differentiation of the surface. These forces produce the unexplained metallogenic features of the various parts of the world; it is probably essential to set up a scientific commission on the problem with the task of performing deep borings.

Contributions to the discussion on the report were made by Academicians N. M. Strakhov, D. V. Nalivkin, A. P. Vinogradov, K. I. Satpayev, D. S. Korzhinskiy, and E. K. Fedorov, by M. A. Kashkay (Academy of Sciences of the Azerbaijan S. S. R.), and by Drs. F. A. Makarenko and V. I. Vlodarets. These recognized the need to reorganize the Division, and especially to include teams concerned with geophysical, geochemical, and biostratigraphic studies. There is a need to extend work on the geology of the earth as a whole; geologic theories can be based on the extensive information accumulated by Soviet workers in the last decade as a result of large-scale geologic exploration.

The conference adopted resolutions that incorporate proposals made by the secretary and by those contributing to the discussion.

The conference was also addressed by Academician D. V. Nelivkin on "The 21st Session of the International Geological Congress" (see No. 1 for 1961 for a preliminary communication on this topic) and by Academician A. P. Vinogradov on "Geochemistry and age determinations abroad" (this communication will appear shortly in this journal).

The decision on organizational questions were as follows.

1. E. L. Krinov is awarded the degree of Doctor of Science honoris causa.

2. Associate Member A. V. Peyve and Dr. I. V. Popov are appointed to the Headquarters of the Division.

3. Associate Member A. V. Peyve is appointed director of the Geological Institute; Associate Member L. V. Pustovalov, director of the Laboratory of Sedimentary Mineral Resources; and K. S. Mogatayev, director of the Institute of Geology, Dagestan Branch of the Academy of Sciences.

CONFERENCE ON POSTMAGMATIC OROGENY, CZECHOSLOVAKIA, 1963[5]

The Central Geological Institute of Czechoslovakia announces that a conference on postmagmatic orogeny will be held in Prague in 1963. Special emphasis will be placed on the geochemistry of ore veins. The organizing committee hopes for extensive representation of foreign specialists.

The conference will discuss especially those problems that Czech workers have specialized in and that are not fully dealt with in the world literature, namely

1. Formation of primary zoning in ore veins, ore deposits, and ore-bearing provinces, and, in particular,

a) conditions giving rise to repeated zoning and to the hydrothermal deposits associated with such conditions;

b) criteria for determining single zoning and the deposits of that type;

c) elucidation of the sources of mineralization (single solution or continuously incoming solution as alternative sources of the various minerals); and

d) evolution of the composition of mineralizing solutions from a single source.

2. Transport of metals by mineralizing solutions, with discussion of the existing ideas on this subject.

3. The pneumolytic phase in the classification of postmagmatic processes.

4. Criteria for detecting metacrysts of ore and other minerals.

5. Role of selective metasomatism in the production of hypogene minerals.

The organizing committee hopes to issue in good time a collection of papers on the above topics and for this purpose invites contributions up to five typed pages in length in one of the languages of the International Geological Congress (figures should not exceed two pages). These contributions must be received by December 15, 1961.

Information on all aspects of the conference may be obtained from the General Secretary M. Stempok, whose address is Central Geological Institute of Czechoslovakia, Prague 1, Malostranke Namesti 19.

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[5] O konferentsii po probleme postmagmaticheskovo rudoobrazovaniya (Chekoslovakiya, 1963), (p. 128).